Capturing Heat Two

Fuel Efficient Cooking Stoves with Chimneys, A Pizza Oven, and Simple Water Heaters: How to Design and Build them

Praise for the Capturing Heat series:
"An excellent book... illustrated, easy to follow... useful for any community."
-Where Women Have No Doctor

By Dean Still, Mike Hatfield, Peter Scott
Aprovecho Research Center

The Capturing Heat Series is dedicated to my supportive and wonderful family. And thanks especially to Kim, my wife, for making it all work. -D.S.

The Capturing Heat Series:

Capturing Heat

Five Earth Friendly Cooking Technologies
and How to Build Them

Capturing Heat Two

Fuel Efficient Cooking Stoves with Chimneys,
A Pizza Oven, and Simple Water Heaters:
How to Design and Build them

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Illustrations by Mike Van, Brian Thomas, Ethan Hughes, Loki Quinnangelis, Cathy White

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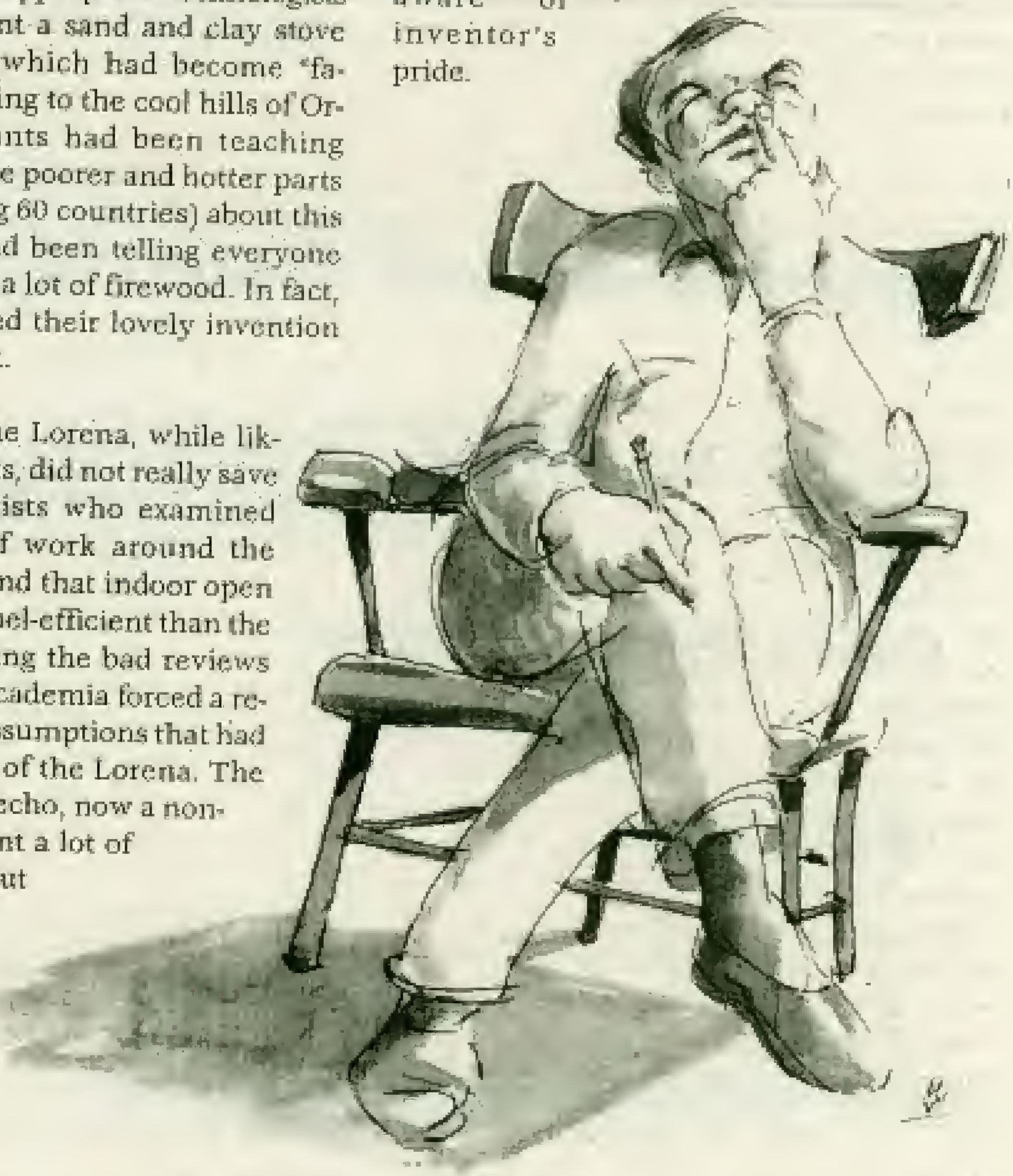
Aprovecho: An Introduction

Aprovecho Research Center has been around since 1981, when a bunch of road-weary (and itchy) consultants to foreign aid agencies, including the Peace Corps, USAID, GTZ, etc., bought 40 acres of land near Eugene, Oregon and began to study seriously what they had once taken for granted as understood. Five years previously, in Guatemala, these appropriate technologists had helped to invent a sand and clay stove called the Lorena which had become "famous." Until returning to the cool hills of Oregon, the consultants had been teaching people all around the poorer and hotter parts of the world (visiting 60 countries) about this neat stove. They had been telling everyone that the stove saved a lot of firewood. In fact, they very much liked their lovely invention and were proud of it.

It turned out that the Lorena, while likable in many respects, did not really save fuel. In fact, scientists who examined Aprovecho's trail of work around the globe frequently found that indoor open fires could be more fuel-efficient than the pretty Lorena. Reading the bad reviews flowing down from academia forced a re-examination of the assumptions that had gone into the design of the Lorena. The researchers at Aprovecho, now a non-profit land trust, spent a lot of time trying to figure out what had gone wrong in this popular design.

Living with a very public mistake helped to dedicate staff to finding out what does work, and then to try to teach about facts, not fads. This formative experience exposed staff to the negative repercussions of bragging about how great an invention performs. It made the new generation of Aprovecho researchers a more cautious bunch, aware of inventor's pride.



The "thinking chair" in the shop was frequently occupied by puzzled looking eco-scientists.

After years of investigation, and consultations with a mechanical engineer who specializes in combustion (Dr. Larry Winiarski), Aprovecho staff began to know a bit more about fires and cooking. Larry's new design, the Rocket stove, coupled with an insulated cooker made from hay or straw, could cook food using one half to one quarter the wood compared to cooking in the traditional way—a fire made between three stones that held up the pot. The road had been long and somewhat rocky. But eventually, experimentation and study did manage to provide a more accurate picture of fire, heat, and how to design stoves. Our new designs use less firewood and produce less smoke.

The *Capturing Heat* series of booklets attempts to summarize what we have learned about Appropriate Technology in the last 19 years. *Capturing Heat One* shares a cooking system that uses both direct and stored solar energy (biomass). Larry has led our investigations into this field. Most of the true "inventions" explained in *Capturing Heat One* are his and the same continues to be true in this second booklet.

Dr. Winiarski is a rare and gifted person. He is a born teacher and hands-on tinkerer, who has gained a feeling for how things work. Aprovecho's investigations into simply-made wood stoves and his explanations of thermodynamics unexpectedly taught our team about a whole range of unexpected applications: from wood stoves to solar cookers and then all the way to solar houses. The role of mass and insulation in stoves and houses became a great concern of the Appropriate Technology staff as we realized that the concepts were frequently misunderstood. Studying how things get hot also seems to have uncovered a few oversimplifications made by some noted solar architects.

Modern instruments, such as pyranometers (that measure sunlight) and data loggers, made it possible for us to measure how well various apparatus worked. We could accurately measure, for instance, what percentage of the energy from sunlight made it into the pots in a solar cooker. Data loggers could track temperatures and relative humidity inside both straw bale and cob walls. Repeated and careful experiments on wood stoves were necessary to determine the success and failure of cherished designs. Our best experiments often resulted in findings that were completely unexpected.

Again and again our expectations were confounded by evidence from experiments. But it was only because of experimenting that designs eventually performed more efficiently. The whole first generation of Aprovecho designs were replaced as evidence pointed out primary errors in design. What became obvious was often in direct opposition to generally accepted beliefs. More than once, our results slammed us against commonly accepted paradigms and it took a while (sometimes a year or two) for us to recognize the implications of the evidence right in front of our eyes.

You are invited to join Aprovecho in an intellectual adventure, one whose goal is the lessening of suffering. The trail of investigation begins with stoves but it continues to solar houses. *Capturing Heat Three* and *Capturing Heat Four* visit heat exchangers, heating stoves, and simpler geodesics, natural houses made from cob and straw and the like. We hope to share some simple math and a bit of thermodynamics so that anyone can analyze and determine what is a fact and what is only a fad. Hyped-up fads concentrate optimism and attention but all too often do not successfully move optimistic people on to viable alternatives.

Given the choice, Aprovecho instructors would much rather teach someone how to be a designer instead of promoting particular

designs. The intention is to give you the necessary facts to, in this case, successfully design wood stoves for baking and cooking and teach you the rudiments of water heating. All of the designs are meant to be "appropriate," which, simply put, means that you should be able to both make and repair the device from locally available, inexpensive materials.

The "best" A.T. design would be the one that can be replicated in most any town around the world, built on site for use locally, and made from vernacular materials. It's preferable if the device is designed on site with local input. A goal of the Appropriate Technology movement is to involve people in the technologies they use. In industrialized countries many people are psychologically removed from the technologies that support them. This distance and lack of understanding can easily result in a feeling of alienation. An important part of the philosophy behind A.T. is to encourage a fondness for and familiarity with designing and living using culturally compatible tools.

Residents at Aprovecho share a common belief in voluntary simplicity. In my case a preference for simplicity stems from mostly selfish reasons. Living with less allows a great deal more personal time to pursue one's own fascinations. It's more fun to accomplish more by needing less. Trying to build things that work, out of vernacular materials available to poor people in various countries, results in very inexpensive experiments. Therefore, lack of money doesn't slow down our progress very much. The "mud-tech" science of helping isn't dependent on grants or tied to direction from funding agencies. We can follow our own crooked-enough noses.

The Research Center

Aprovecho Research Center is located on a 40-acre farm and woodland. There is a beautiful acre-and-a-half garden that provides almost all of our fresh produce. The woods are managed to supply both lumber and firewood for heating and cooking while steadily becoming both healthier and more productive.

Aprovecho classes and research are divided into four main areas: Organic Gardening, Sustainable Forestry, Indigenous Skills, and Appropriate Technology. Our school teaches these four subjects to mostly college-aged or older interns. This book concentrates on A.T., but it is only one fourth, and certainly not the most important quarter, of our investigations into how to live sustainably. (Carl Jung, in a famous rebuttal to Freud's insistence on the preeminence of infantile sexuality, agreed with farmers worldwide when he pointed out that sustenance surely leads the hierarchy of needs.)

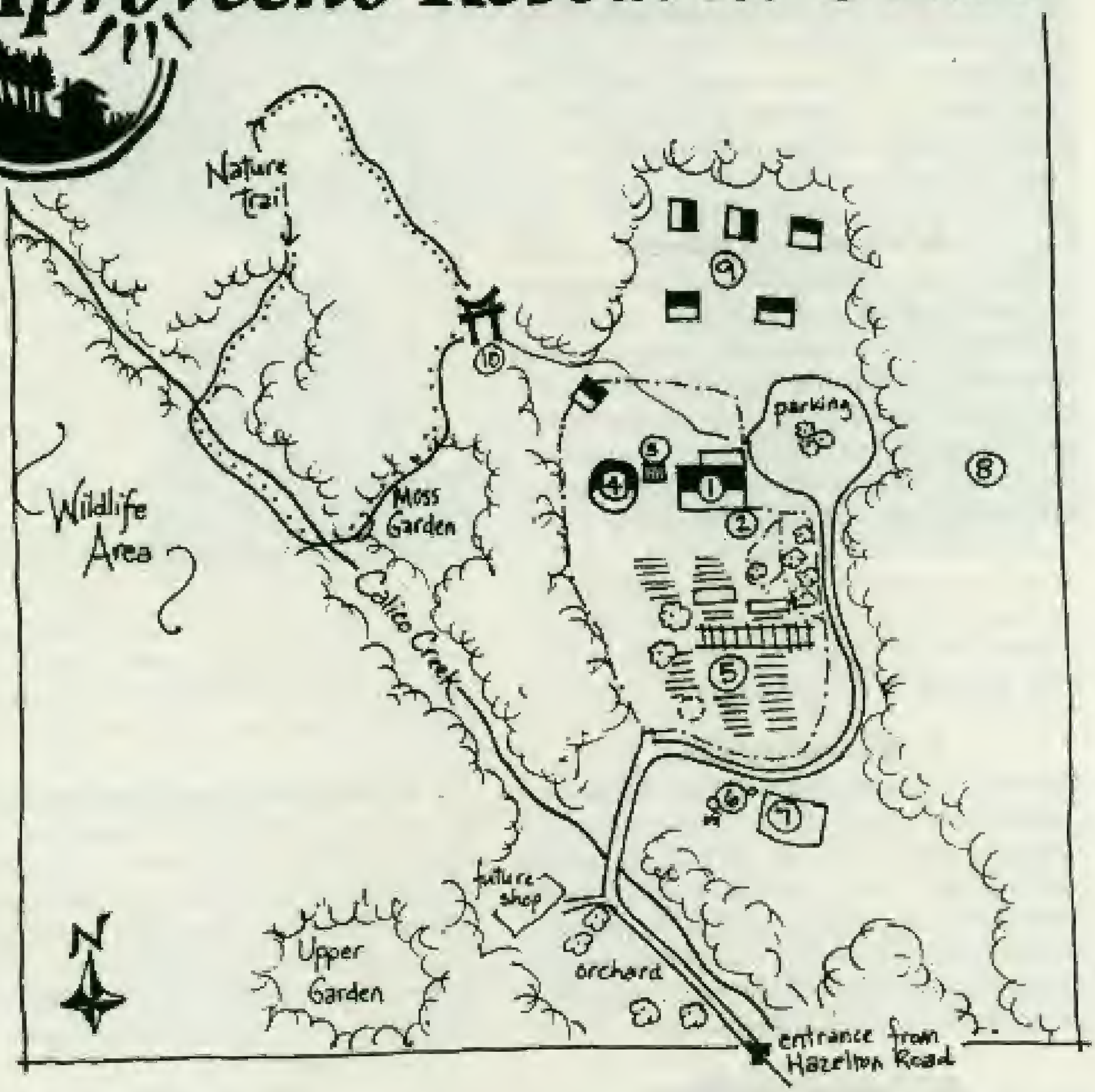
The self-guided tour described here introduces you to some of the major features of the Research Center. Please visit whenever you're in the neighborhood! You're also welcome to come for our monthly Open House, the first Sunday of each month at 2:00 pm, when you can receive a full guided tour of the Center.

Self-Guided Tour

1. Straw Bale Dormitory

This experimental and demonstration building was constructed in 1996-7 with funding from the Oregon Department of Agriculture, the Woodard Family Foundation, the Rose Tucker Charitable Trust, and many generous members of Aprovecho. The post-and-beam framing, built mainly with wood from

Aprovecho Research Center



Aprovecho's forest, supports the structure, while straw bales provide the infill and insulation for the passive solar building. Sensors embedded in the straw monitor relative humidity of the bales in order to determine whether the straw can last in this damp climate. This building is the first of the new campus we are developing in order to become fully up-to-code and accessible as a public facility. The new campus will consist of this experimental straw bale dormitory, a community meeting hall, a shop, and six staff cabins. The goal of the campus is to create housing and teaching facilities that exemplify energy-efficient, solar-assisted, ecologically-friendly building techniques.

2. Photovoltaic Modules Create Electricity

A 1.6 kilowatt photovoltaic system donated

by Enron is mounted on the roof of the dorm with a few modules on the ground for visitors to look at more closely. We're working with Enron as well as the two local utility companies, EPUD and EWEB, to determine the efficiency of these modules in this mostly cloudy region. The system is connected to the grid via an intertie. We both buy electricity from, and sell it to, the utility.

3. Outdoor Kitchen

Here we do outdoor cooking, appropriate-technology style. Often you'll see Rocket Stoves made out of recycled cans, a bread oven based on the same design as the Rocket Stove, and some of our most recent stove prototypes resulting from recent work in Honduras and other countries. The most recent stoves combine the high efficiency of the Rocket Stove and the beneficial chimney (which gets smoke out of indoor kitchens). Look around the area and you'll see solar cookers that are used in the summer for a great amount of our cooking.

4. Rotegrity Shop

This temporary shop provides a mostly dry space with a minimum of expense. The rotegrity design is an adaptation of the Buckminster Fuller geodesic dome, but has overlapping structural bars. This structure was built for just a few hundred dollars, plus the tarp. Aprovecho will be building a more permanent shop as funding allows.

5. Organic Garden

Our garden provides almost all of the fresh food used to feed the approximately twenty people who reside at the Research Center. All of the work done in the garden is performed with human power and without the use of chemicals. Resident interns, under the direction of gardening instructors, prepare the beds, raise starts, and care for their vegetables until harvesting. They incorporate techniques including raised beds, crop rotation, companion planting, edible weeds, vermiculture, composting, and much more. Many of the trees located throughout the garden are volunteer plum trees, and a stroll through the grape arbor in late summer is an experience not to be missed. The ducks patrol the eastern side of the garden in search of our greatest enemy—the slug. Two greenhouses extend our growing season, allowing for melons and more in the summer and fresh greens all through the winter. We also start the majority of our plants in the greenhouse, away from the hungry mouths of slugs. Two fenced areas in the northeast corner of the garden also act as young orchards and space for our chickens to roam. Water for the garden comes from a spring via a gravity-fed system with no moving parts. Head to the southwest part of the garden to sit for a spell in the contemplative garden circle, noticing the beds filled with perennial medicinal and edible herbs. Then go through the vine maple gate (closing it behind you to keep out the deer!) and turn left onto the road. The small enclosed area to your right contains young blueberry bushes.

6. Rest and Relaxation Area

We come here to unwind, sitting around the campfire, floating in the wood-fired hot tub, or taking a "cannibal bath" in the Rocket Stove-powered bathtub. Or maybe in the summer it'll just be a quick solar shower with water from the batch solar heater. Closer to the creek there is also a Rocket Stove sauna.

7. Goat Pen

Goats (Nestle and Lulu) provide the community with a supply of fresh milk and friendly hoofed companionship.

8. Pole Forest

As you continue up the road, off to your right you can see part of the twenty (out of our thirty-five) forested acres that serve as the production zone. This land was clear-cut approximately forty-five years ago and naturally re-

generated, leading to dense growth. Our forester thins out trees, using the wood for building, firewood, and sometimes for sale. Cut logs are pulled out by a team of draft horses and sawed with a portable sawmill. We are working towards creating a managed old-growth forest, leaving important biomass on the forest floor in order to continue building layers of humus. Snags are left standing to attract birds. You'll often hear the loud cry of the Pileated woodpecker echo through the woods. Wild mushrooms, such as chanterelles, thrive in this type of forest and you might find some during the fall season. Behind the small green structure in the parking lot, you can also see some of our cultivated mushroom operations. Fifteen acres on the northwest part of the property are a designated Wildlife Area where no cutting occurs. In this area especially, watch out for the three shiny leaves that indicate poison oak.

Aprovecho Interns

9. Staff Cabins

Continuing up to the parking lot, you'll be able to see up the hill where six staff cabins will eventually be located (two are already there). This co-housing area will allow up to twelve staff to live on-site, providing private sleeping quarters, with communal activities continuing to happen in other buildings. Grants from the Meyer-Memorial Trust, the Collins Foundation, and the Jackson Foundation, as well as generous member donations, are allowing for this construction. We are using environmentally-friendly building techniques as much as we can, while pointing out that the size of a structure is crucial in terms of resource consumption. Here specifically, wood is the most bioregional building material available. We stress local and appropriate building materials, encouraging houses that are well-insulated and passive solar in design.

10. Nature Trail

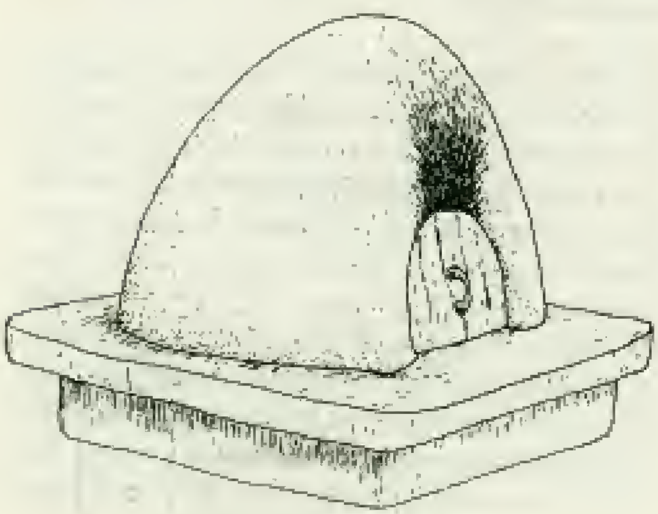
This short 1/3-mile trail leads you through our designated Wildlife Area and back out into the production zone of our forest. Follow the trail north of the dorm that goes through a wide gate and west into the forest. Look for the beautiful wooden Torii gate that marks the start of the trail. The walk goes through the Moss Garden and other pristine quiet spots that are a source of inspiration and rejuvenation for our community. Enjoy!

The Pizza Oven

(Analysis of Retained-Heat Baking)

Traditional High-Mass Bread Ovens

Both plain and fancy bread ovens can use retained heat for cooking. Fire heats up rocks or bricks or earth or the cement walls of an oven. When the mass is hot enough the food is placed inside the oven to be cooked. High-mass brick pizza ovens made the gourmet pizza I loved to sample in San Francisco. The English traditional bread oven and the Navajo beehive earthen oven are also based on first heating mass and then using the stored heat to cook food.



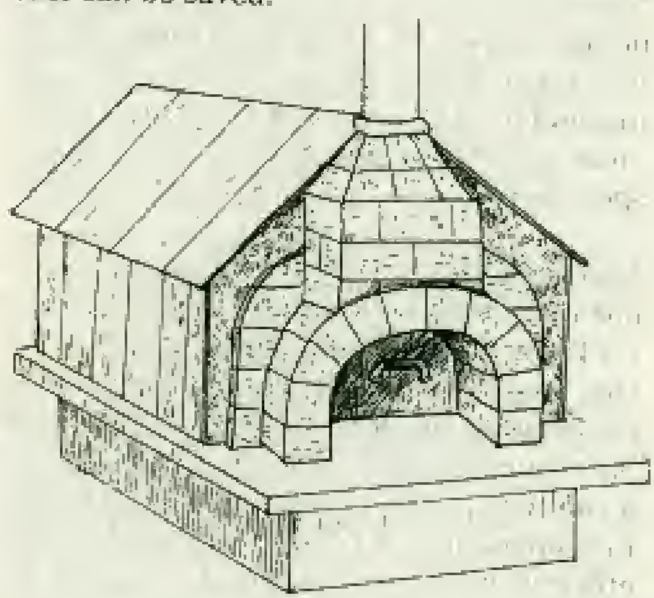
Navajo Beehive-Style Oven

Experimentation shows, however, that heating air, which then directly heats food, is usually a more fuel-efficient way for a family to bake food.

The trick to making a good low-mass hot-air oven is to put the heat where you want it without *a.) losing the heat into the body of the stove* or *b.) letting the heat escape up the chimney*. We want the heated air to cook food!

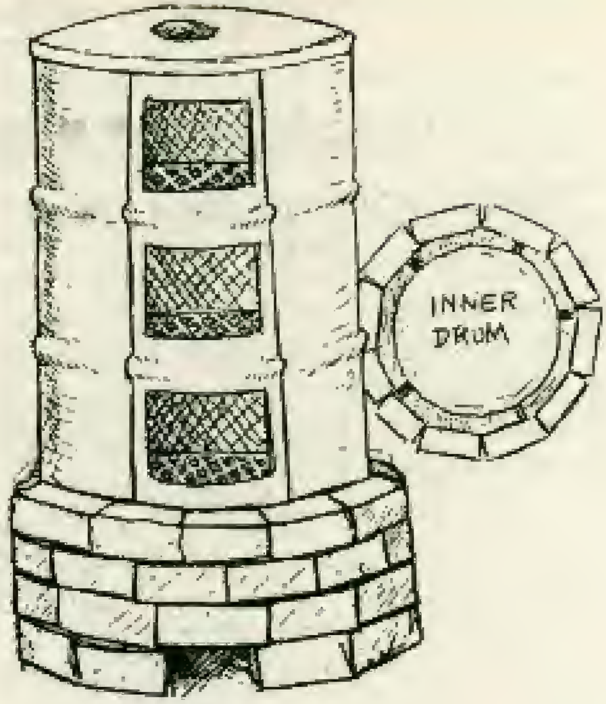
Trying to optimize a retained-heat oven is a bit more difficult. It needs the right amount of mass to store the right amount of heat. Also, without insulation on the outside of the thermal mass, heat easily dissipates, so that retained heat is lost before it can be efficiently used.

Earthen stoves can use so much wood, to bake so little bread! At the very least, earthen stoves can be covered by insulation (wood ash, rock wool, fiberglass, etc.) so that the heat isn't as easily lost. But to be truly efficient the interior surface of the oven also needs to be optimized to absorb most of the heat from the fire and reduce exit temperatures out of the chimney. An earthen oven usually requires split logs fed into it for long periods of time to reach cooking temperatures. When people learn that it is possible to use a little fire to directly heat bread, it is amazing how much fuel can be saved.

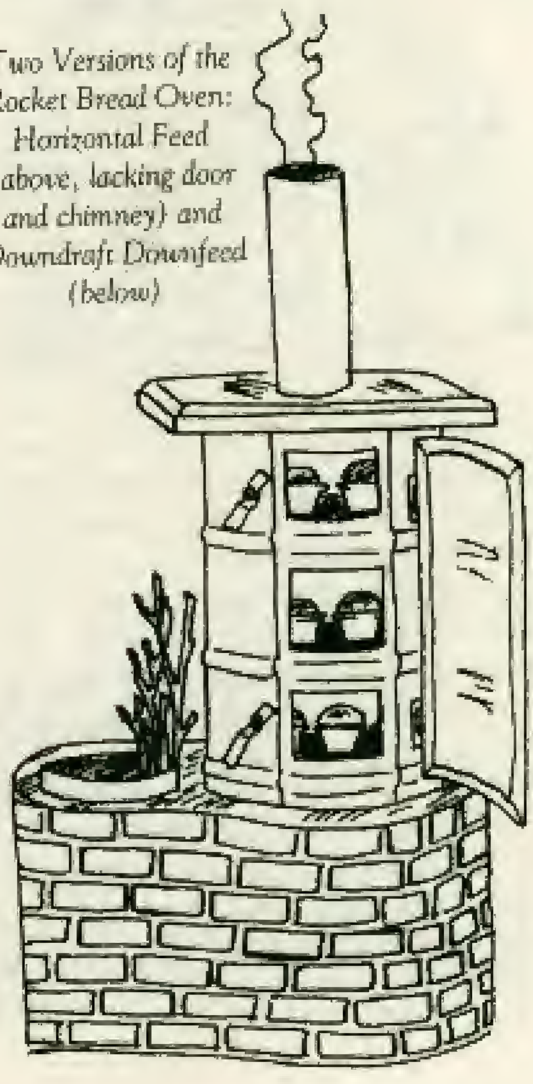


The English Bread Oven

More than ten years ago Alan Scott (*The Bread Builders*, 1999) visited Aprovecho and built an early version of his retained-heat English bread oven. People had a great time cooking in it for a whole day after it was brought up to temperature. I remember all of us getting stuffed with bread, cakes, pastry, etc. It was a wonderful time. Alan was experimenting with high-mass retained-heat bread ovens for commercial applications. He figured that Aprovecho might be able to use an oven meant for constant use since we baked food almost every day.



Two Versions of the Rocket Bread Oven: Horizontal Feed (above, lacking door and chimney) and Downdraft Downfeed (below)



The Rocket Low-Mass Bread Oven

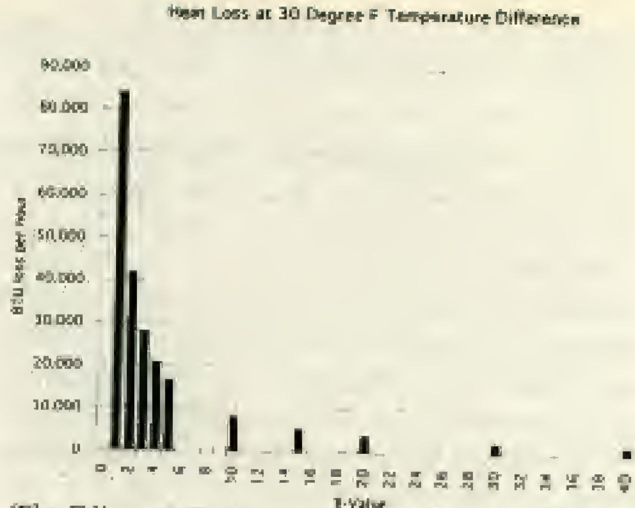
Over the years, we used both Alan's English Bread oven and an earthen oven for baking bread. No one questioned the wood use because we had nothing to compare it to. Then Larry built a low-mass hot-air bread oven right in between the two high-mass models.

We tested Larry's Rocket oven one night before a visit from thirty, usually hungry, Humboldt State students. (Humboldt State College in California, like Appalachia State in North Carolina, offers an Appropriate Technology major.) We made 66 pounds of bread that night in one firing, weighed after baking, and used 11 pounds of wood to do it. The bread quality seemed the same but we used spectacularly less fuel to feed our visitors.

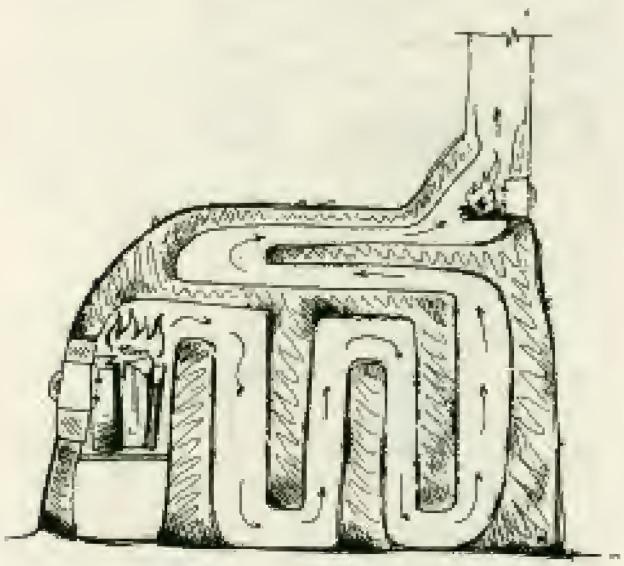
Experience has shown that retained-heat ovens often suffer from two classic problems: 1.) There's not enough exposed internal surface area to lower exit temperatures during the heating up period. There is inefficient heat transfer to the oven. The little cave with a chimney on top that forms the Navajo beehive bread oven is not convoluted like a fuel-efficient high-mass heating stove. (See diagram.) Too much of the heat just shoots up the chimney, in this case. A better heat trans-

fer necessitates more optimized surface area.

Then, 2.) high-mass ovens can have insufficient insulation to keep the heat doing work for as long as possible. A few years ago, Alan changed his design and added insulation, which helps a lot. We would want perfect insulation around the mass if possible. In that way the captured heat would be put to best use. Any amount of insulation will increase the benefit gained from heat retention, but it's great if an oven has an insulative cover with a rating of R-10 or better.

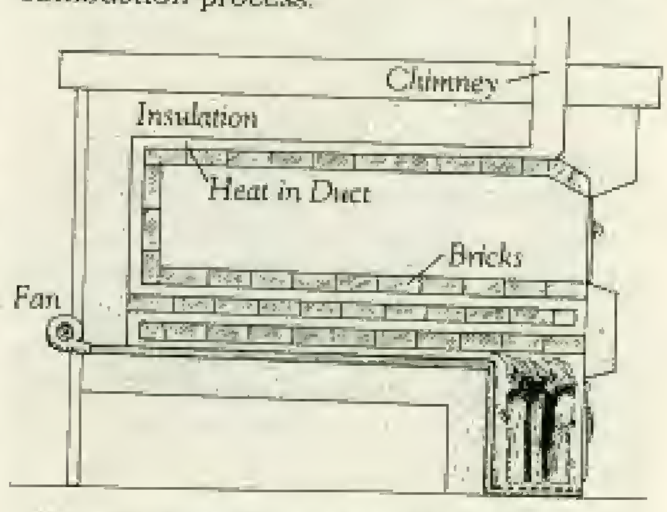


The Effect of Temperature on the Passage of Heat through Insulation


High-Mass Heating Stove

The great advantage of retained heat ovens is that after the mass is sufficiently warm, the chimney can be completely closed. With the door closed as well, heat is not lost up the chimney. Keeping heat in the oven can improve the efficiency. In practice, however, it is first necessary to remove all coals and potentially smoldering material since smoke will ruin the bread and possibly leak into the room. Sweeping out the burning fragments is a messy job. But it should be remembered that completely shutting down the draft while continuing to cook is possible only in retained heat ovens.

The spring '99 class at Aprovecho designed a "best case" retained-heat oven and started building the prototype. It has 72 square feet of surface area where heat rubs against the mass to lower exit temperatures out of the chimney. As a rule of thumb, it takes at least 75 square feet of exposed mass surface area to adequately absorb the heat from a fire, i.e., to lower temperatures from around 2,300 degrees Fahrenheit (the temperature of yellow flame) down to minimum exit temperatures of around 250 degrees Fahrenheit. The student's oven is insulated to R-40 so that the heat isn't lost very quickly. Air is preheated as it is pushed by a small fan to aid in the combustion process.



Summer '99 Best Case High-Mass Bread Oven

In a fuel-efficient retained-heat oven we have to design in the right amount of mass. If we use too much mass we will have to waste Btu's to raise more mass than necessary up to baking temperatures. The oven stays warm longer than necessary. The thermal load (the amount of food we wish to cook) needs to be matched to the amount of retained heat. Conversely, if we use too little mass there won't be enough retained heat at baking temperatures to cook the bread. Heat below 350 degrees F. starts to be too cold for normal bread baking. Heat at greater than 450 degrees will usually start to burn bread.

As a rule of thumb, most materials used for mass in stoves will hold *about .2 Btu's of heat for each degree of temperature rise (Fahrenheit)*. Our tests show that it takes something like *350 Btu's per pound to bake bread*. Aprovecho has an average of 25 daily mouths, firmly attached to souls clamoring for knowledge, who also lust for bread.

Using these formulas, let's practice together and design a bread oven that will retain enough heat (at a temperature between 350 and 450 degrees F.) to bake 12 loaves of bread. Only the heat at the correct temperature helps in baking bread. Each loaf weighs two pounds.

1. 24 pounds of bread will require 8400 Btu's of heat energy to bake. (24 pounds x 350 Btu's/pound = 8400 Btu's.)

2. A 100-degree temperature rise (350 to 450 F.) in one pound of earth or brick stores about 20 Btu's. (100 degrees F./pound x .2 Btu's/degree F. = 20 Btu's/pound.)

3. Dividing 8400 by 20, we find that we need approximately 420 pounds of thermal mass to store the amount of needed heat. (8400 Btu's ÷ 20 Btu's/pound = 420 pounds.)

In other words, the heat needed (8400 Btu's) to bake 24 pounds of bread will be released when 420 pounds of thermal mass drops in temperature from 450 degrees to 350 degrees F.

This heat must be well insulated so that it is forced into the bread instead of lost while heating cooler exterior air. The efficiency of heat transfer to the mass will, in large part, determine how much fuel is burned to bring the oven up to temperature. But even in an insulated convoluted retained-heat oven, the Btu's required to raise temperatures up to the point where baking commences are wasted! Typically, at 350 degrees F. and below, the oven's large store of retained heat is not put to any useful purpose. Unless the family is well-organized and ready with a project that uses a slow oven, all the energy spent in heating the mass up to 350 degrees F., while necessary to allow baking to begin, is ultimately lost when the oven cools down.

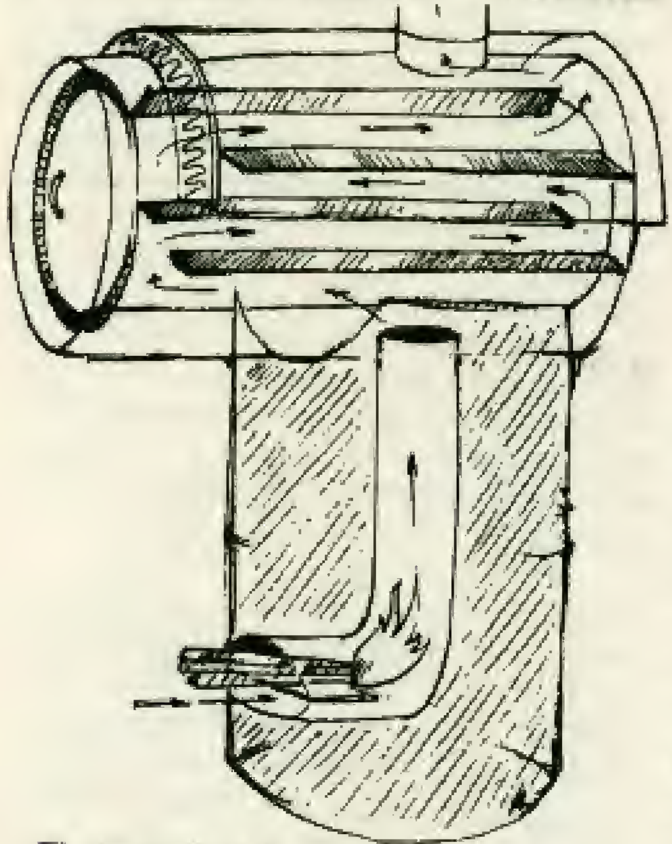
If the oven is designed to cook a thermal load of 24 pounds of bread, a lot of heat is also left unused when the chef prepares only 12 pounds. On the other hand, such an oven cannot bake 48 pounds of bread without a refiring. Designers usually, therefore, make very heavy ovens that can handle a lot of bread. Obviously, if the retained heat and thermal load are not sized in relation to each other, fuel efficiency suffers.

In the same manner, we can imagine that the amount of thermal mass added into a solar house probably needs to be sized to the input of sunlight-generated Btu's, if we want unassisted sunlight to heat the house.

Let's leave mass behind for a moment and consider the low-mass oven in which hot air directly cooks food.

The air is forced to rub against the inner drum that forms the oven. Hot air moves in a maze over the oven, so that, at the end of this cir-

cuitous route, exit temperatures are relatively cool. The annulus is created by splitting another 55-gallon drum lengthwise and sliding it over the first, leaving a 3/4" gap between the two drums. The heat passes through this gap and rubs against the bottom, sides, and top of the inner barrel that contains the bread.



The Rocket-Style Pizza Oven with Big Door

The maze is made up of sausage-like sections of fiberglass bat insulation covered by three layers of aluminum foil. The Pizza oven is also well insulated, both around the combustion chamber and the oven itself. This oven is essentially the same as the vertical bread oven featured in *Capturing Heat One*. Laying the oven drum on its side allows us the use of the reclosable lid as a door, so that a large tray of pizza can enter. The fire is also closer to the oven than in the vertical Rocket Bread Oven.

This low-mass oven gets up to 400 degrees F. twenty minutes after the fire is started. Temperatures are controlled by the amount of sticks inserted into the combustion chamber. Combustion continues only as long as the food is cooking, and then the fire is extinguished.

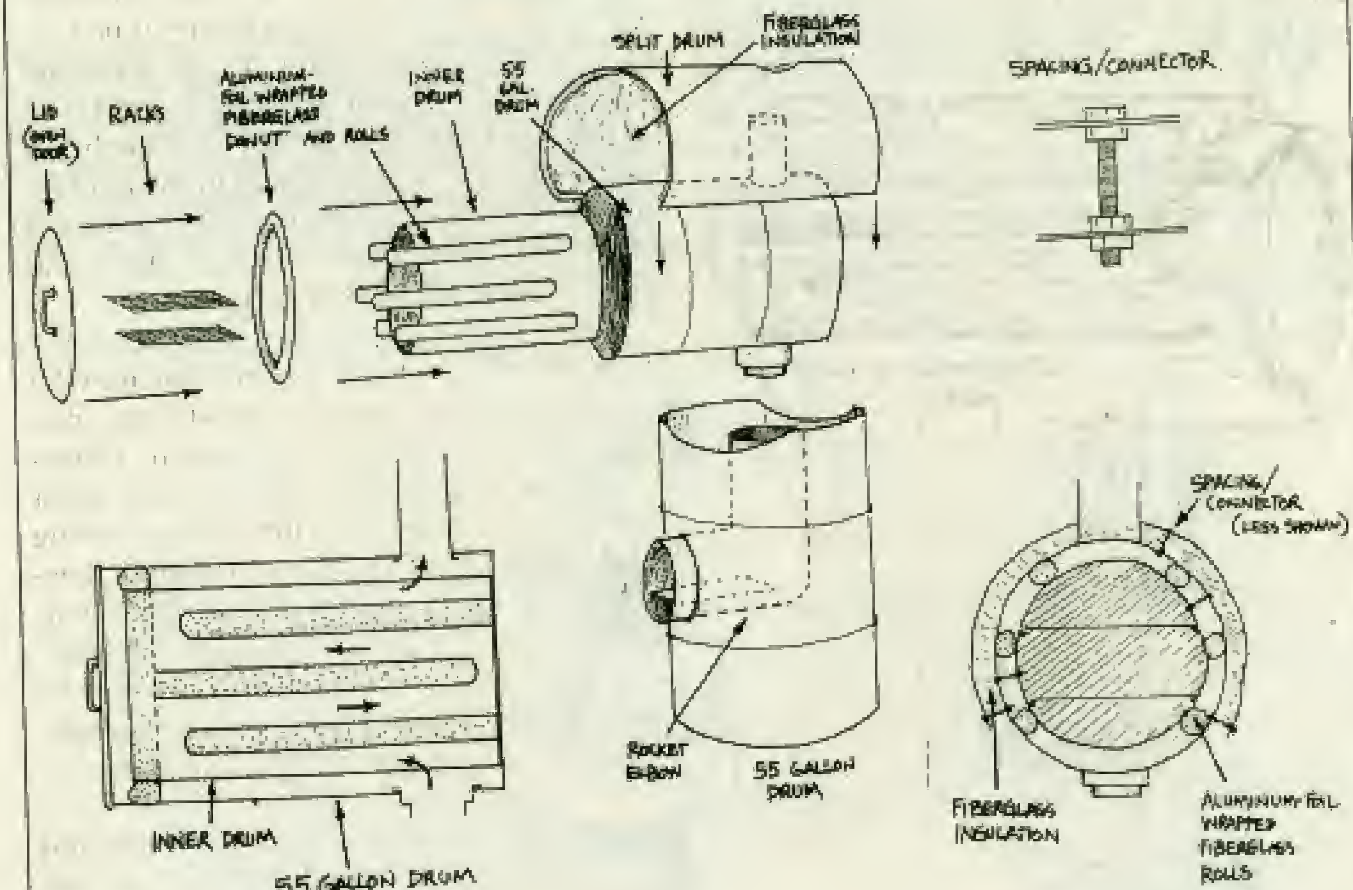
Experience shows that a low-mass air-heating oven is a good match for family-type baking. The temperature curve in the low-mass oven is almost straight up to the desired temperature and then straight down as the fire is extinguished. The stored heat in even a perfectly insulated retained heat oven is wasted at both ends of the curve when it's above and below the desired baking temperature.

There are aficionados of specialty breads who are sure that retained-heat bread tastes better. It may be that for a certain taste a high-mass oven is necessary. But we have great cooks at Aprovecho who make great-tasting bread. Most bread is baked in regular low-mass hot-air ovens. Massive ovens seem better suited to commercial situations where they are in constant use. The mass will keep the commercial oven at a very steady temperature, which is important for product reliability.

However, most families can cope with and ignore slight imperfections. (Heck, I grew up in a family!) Because they save fuel, and are easy to build and fun to use, we can wholeheartedly recommend low-mass ovens that heat air that then cooks food. The vertical oven (*Capturing Heat One*) and the horizontal oven presented here are variations on a theme.

It's nice to have a ready-made big door as in the Pizza Oven. But the original vertical oven is a great introduction to the wonders of fuel-efficient wood-fired ovens, as well. The Pizza Oven is slightly more fuel-efficient because the fire is closer to the bread. The hot flue gases also follow a more circuitous route around the inner oven. But for this reason, a higher chimney is required to reinforce the draft. Of the two, the Pizza Oven is a bit easier to build. Give it a try!

How to Build the Pizza Oven



A handle is attached to the removable lid of the 55-gallon drum.

Two shelves are inserted into the 33-gallon drum. We used chicken wire stretched tight and bolted into the sides of the 33-gallon drum.

A donut made from three layers of aluminum foil wrapped around fiberglass insulation seals the gap between the 33- and 55-gallon drums.

Long sausages made from three layers of aluminum foil wrapped around fiberglass insulation form the maze through which heat is forced to travel.

A 55-gallon drum split longitudinally covers the top of the oven, protecting the fiberglass insulation that lays on top of the oven.

The rocket elbow can be made from 8"-in-diameter stove pipe or elbow.

Cooking Stoves with Chimneys

When appropriate technologists began to look at the fuel efficiency of three-stone fires, an assumption was made that favored the new stoves they were introducing. The three-stone fire was viewed as "very wasteful of fuel." (*Wood Conserving Cook Stoves*, VITA, 1980). Early estimates of the efficiency of the open fire were very low, usually between 3% and 7%.

These estimates can be true of open fires, which are outside in the wind. But many people either cook inside or protect the fire from wind. In these cases, the three-stone fire performs more efficiently. Expert users can get reasonably high efficiencies from their home cooking fires.

"Looks to me like a preference for an open fire has a lot more going for it than just the conservative nature of tribal societies!"

Our latest Spring 1999 experiments with the three-stone fire resulted in an average fuel efficiency of 11.2%. (11.2% of the heat made it into the pot.) The testers were amateur US College students who were trying to do their best. Trained fire operators can usually do better. Even the amateurs sometimes scored much higher than their average. The range of scores in ten tests was from 7.6% to 17.8%. Experts would obviously tend to score in the higher ranges of efficiency.

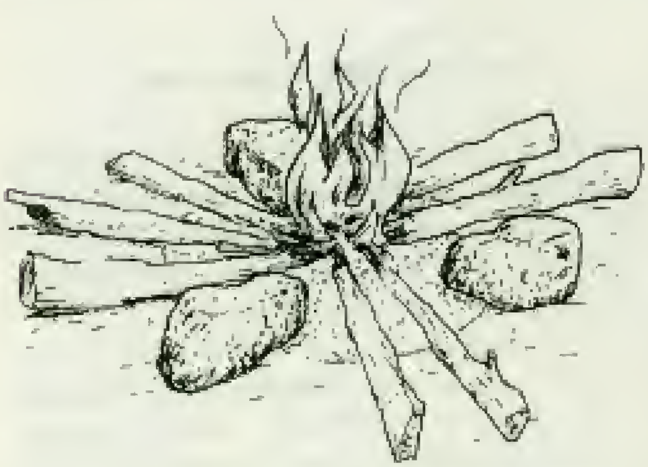
The Advantages of the Open Fire

How can we design a stove that beats the open fire? First, let's list the advantages of the three-stone fire when compared to some stoves:

• No heat is absorbed into the mass of a stove body. High-mass stoves can absorb heat that could have gone into the pot.

• Fire hits the bottom and sometimes the sides of the pot, exposing a lot of the pot to the heat.

• Sticks can be fed in at the appropriate rate, assisting complete combustion.



The Amazing Three-Stone Fire

How to Achieve More Complete Combustion

Every stove suffers because it has some mass. But a stove can achieve better combustion than an open fire. The good stove helps to make hotter and more efficient fires by doing the following things:

• Insulates around the fire. A hot fire burns up more of the combustible gases and produces less smoke.

• Limits the cool air that lowers temperatures in the area of combustion.

• Pre-heats the air before it enters the fire.

• Forces the user to meter the fuel.

• Forms a grate out of the sticks of wood.

• A chimney creates draft, assisting combustion.

• Escaping smoke passes through flame and combusts.

How to Get More of the Heat Into the Pot

Although flames sometimes touch the pot pretty efficiently in an open fire, the stove can improve upon the efficiency of heat transfer in the following ways:

• Force the heat to contact as much of the pot as possible. Increase the maximum surface area exposed to hot flue gases. Make heat rub against the pot's surface.

• Insulate around the fire everywhere except where it touches the pot(s).

• Make the heat contact the pot(s) for as long

a time as possible. Prolong the dwell time. (See the Pizza oven.)

• A greater percentage of the heat enters the pot if there is as large a difference in temperature as possible between the pot and the heat source.

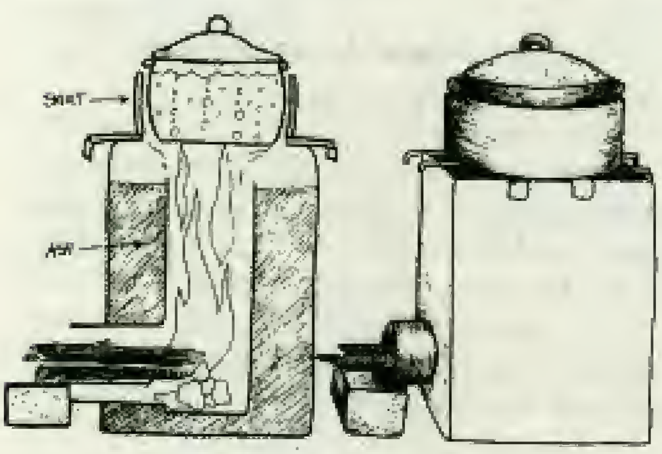
• It helps if the pot is as conductive as possible.

• Increase speed of flue gases so they hit the pot harder.

The Rocket Stove

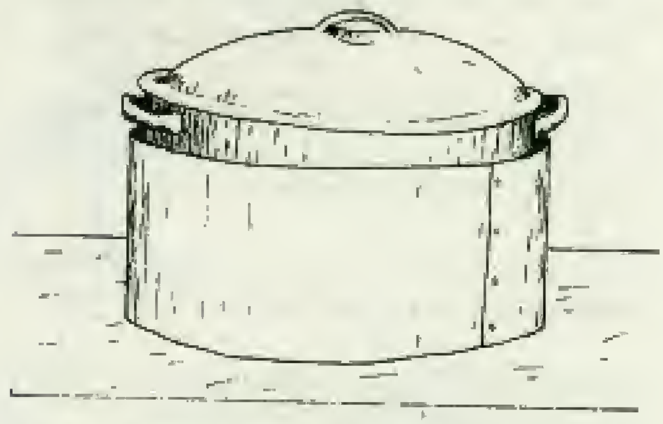
The Rocket Stove is designed to do all of the preceding things to both a.) achieve more complete combustion and b.) force as much heat into the pot as possible. The Rocket stove attempts to burn up as much smoke as possible and then uses a skirt to force the hot flue gases to rub against both the sides and the bottom of the pot. The Rocket stove is also made with low-mass materials if available and is well insulated, if possible.

Forcing the hot flue gases to rub against the pot is very important when trying to save fuel. The Rocket stove, by itself, cleans up a lot of the smoke from a fire but it is only about as fuel-efficient as a well-run open fire. In amateur tests conducted in the spring of 1999, the Rocket stove without a skirt averaged 12.5% efficiency. (Again, experts can score higher.)



The Rocket Stove

But, when a skirt was added (a simple cylinder of metal around the pot, under the handles) the average amateur efficiency rose to 23.6%. The skirt is very important for fuel efficiency. The heat passes through a very small gap, usually 1/8" to 1/4", between the skirt and the pot and is forced to scrape against the pot, increasing heat transfer. In fact, fuel efficiency in a stove is usually much more affected by heat transfer to the pot than it is by improving combustion efficiency.



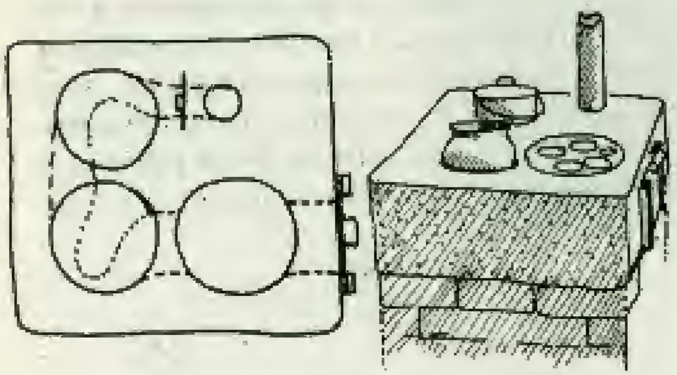
A Skirt Greatly Improves Heat Transfer to the Pot

Stoves with Chimneys

The Rocket stove tries to reduce smoke by improving combustion. But if people are well-off enough to afford a chimney, then all smoke can be removed from the living quarters.

The old Lorena stove had one great thing going for it. All of the smoke was transported from the kitchen in a chimney. Inhaling smoke is very bad for one's health, so even though the Lorena wasn't very fuel-efficient, smoke removal was a great contribution in and of itself.

In fact, there are many NGO's including the World Health Organization who might conclude that removal of smoke is more important than fuel efficiency. Recent studies confirm what has been obvious for decades. Inhalation of smoke does cause a host of medical problems including very serious respiratory illnesses. Breathing wood smoke is dangerous. It is very important to reduce exposure to smoke, especially for children!



The Mud and Sand Lorena Stove

Problems with the Lorena Stove

The Lorena stove was originally designed by a group of volunteers in Guatemala including consultants from Aprovecho. Ianto Evans, a founder of Aprovecho, wrote the book *Lorena: Owner-Built Stoves* published by Volunteers in Asia in 1979. The Lorena continues to attract friends but there are several problems in the Lorena design that have been corrected in later Aprovecho stoves with chimneys. These problems are:

• The fire directly contacts the very heavy mass of the stove body, which absorbs heat, robbing it from the pot.

• The combustion chamber is uninsulated. The cold walls cool the fire, causing smoke.

• The fire flow path does not intimately touch the pots. It flows horizontally past the pot, resulting in poor heat transfer. The walls of the fire tunnels are uninsulated.

Earth Is Not Good Insulation

Before experimentation proved us wrong, Aprovecho stove designers thought that earth was insulation. We did not fully understand the difference between mass and insulation. Good insulation is made up of little pockets of air separated from other tiny pockets of air by a lightweight, relatively non-conductive material.

Earth, especially rammed Lorena, doesn't contain many pockets of air. Good insulation resists the passage of heat; thermal mass does the opposite, absorbing heat. Instead of using sand and clay near the fire now, Aprovecho designers use natural insulation, like wood ash. And instead of rushing the fire past the pots, the new designs force the hot flue gases to rub against the metal surface, which greatly increases heat transfer.

The retained heat in the stove body does not assist in cooking since the pot is hotter than most of the surrounding mass. Once the stove absorbs heat, it is mostly diverted and lost. For fuel efficiency, it is important to insulate the entire heat flow path.

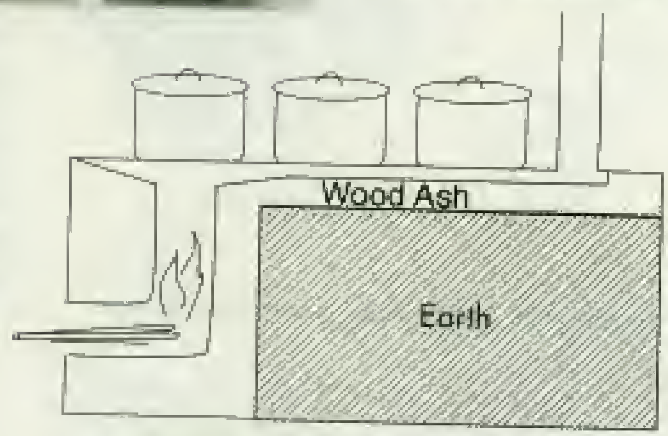
The Dona Justa Stove

In 1999, Aprovecho was invited to assist two non-governmental organizations in Honduras to design and help build a stove that has a metal griddle covering the stove's top. This plate of steel is called a "plancha" in Spanish. The original Honduran plancha stove was designed in 1995, with help from Rogerio Miranda and PROLENA. Stoves like the Dona Justa have been built in various places around the world; this type of design is not new.

Left: A Honduran family enjoys its new stove.

Tests show that this stove is about 19% efficient. The plancha griddle is good at transmitting heat to the pots. The thin metal is a great conductor of heat. But, for the same reason, wherever the plancha is open to air, where it isn't touching the bottom of a pot, heat easily leaves and heats the room instead. However, 19% is an improvement over the open fire, and no smoke should enter the kitchen. Pots that are heated on top of the griddle stay clean, which is very important to certain cooks.

The Aprovecho version of the plancha stove includes a Rocket-type insulated firebox and chimney. Hot flue gases are also forced to pass directly underneath the metal griddle. The following diagram points out the design features of this type of improved plancha stove named after Dona Justa. (Mrs. Justa helped to design, build, and test this stove in Honduras.)



The Dona Justa Stove

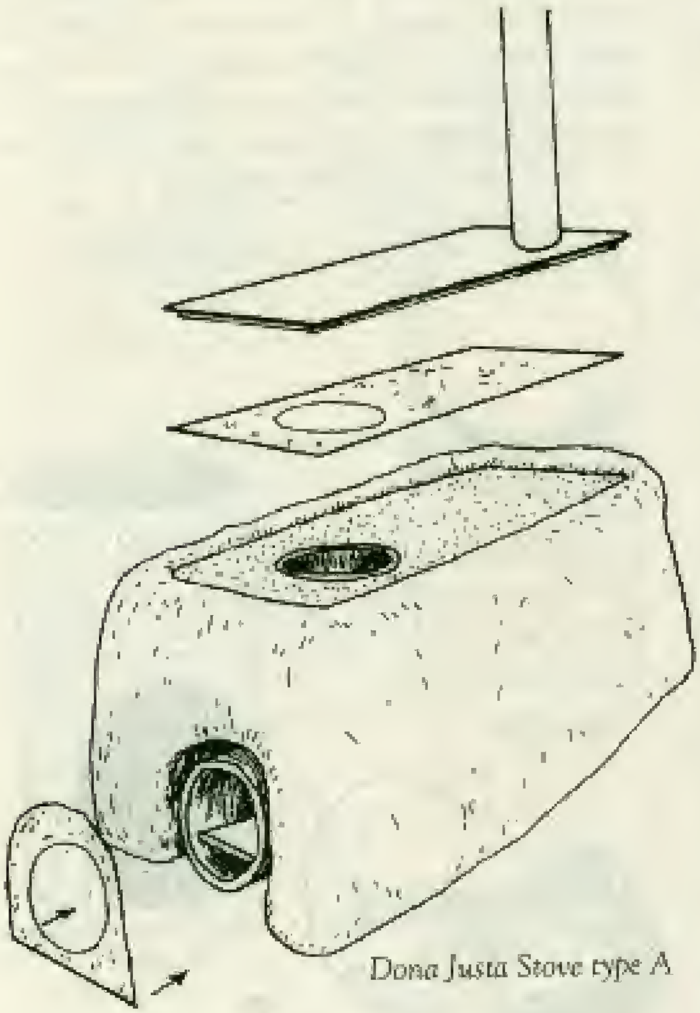
Mike Hatfield (far right) and women of Nueva Esperanza, a co-op in Honduras which makes durable stove parts

The Justa stove does many of the same things that the beautiful

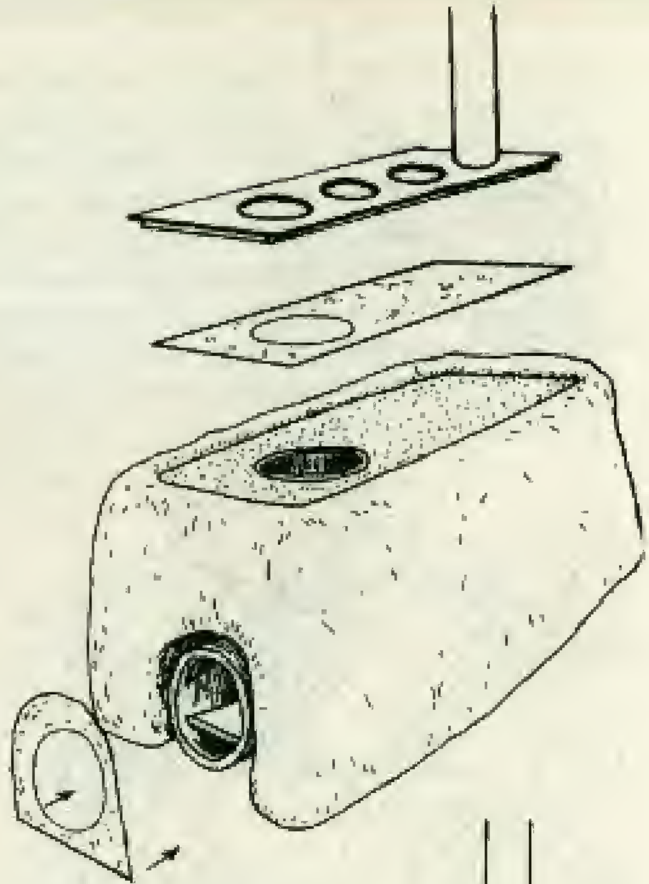
old cast-iron cooking stoves did. These older-type stoves now cost more than a thousand dollars in the US. But a Justa stove can cost less than 20 dollars to make. We plan to install this stove and one quite like it in the kitchens at Aprovecho, reducing our use of propane.

How to Build Three Variations of the Dona Justa Stove

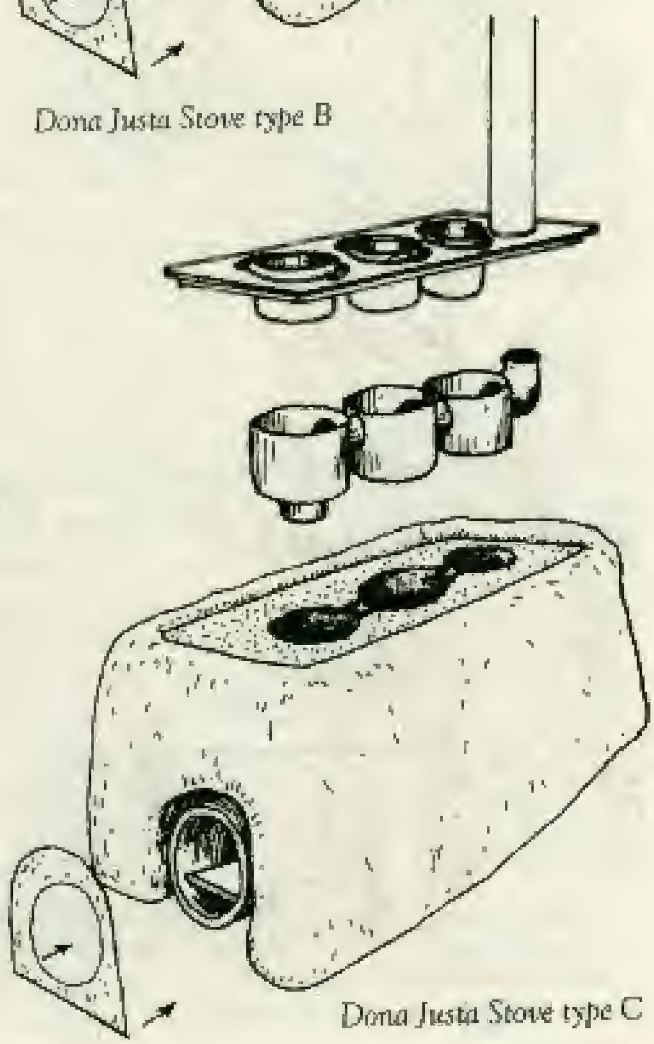
The pots can sit on top of the griddle (A), be placed over holes cut in the griddle (B), or be partially submerged into the griddle (C).



Dona Justa Stove type A

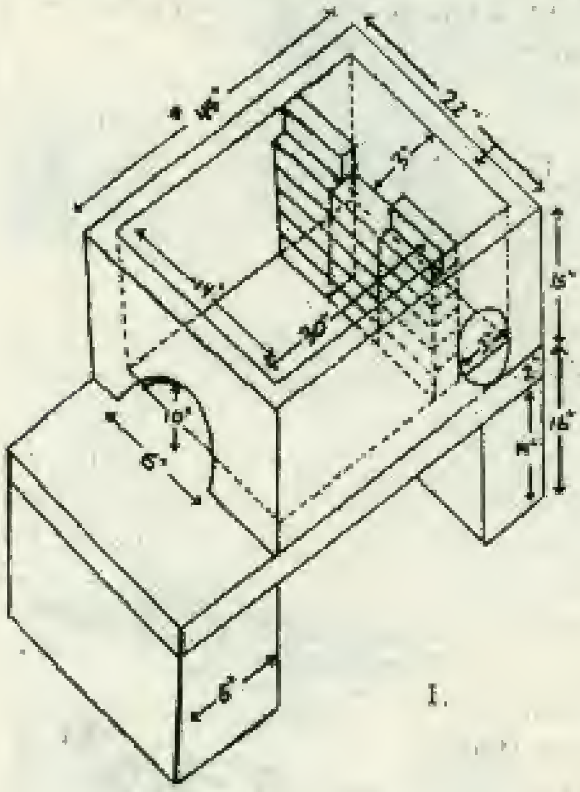


Dona Justa Stove type B



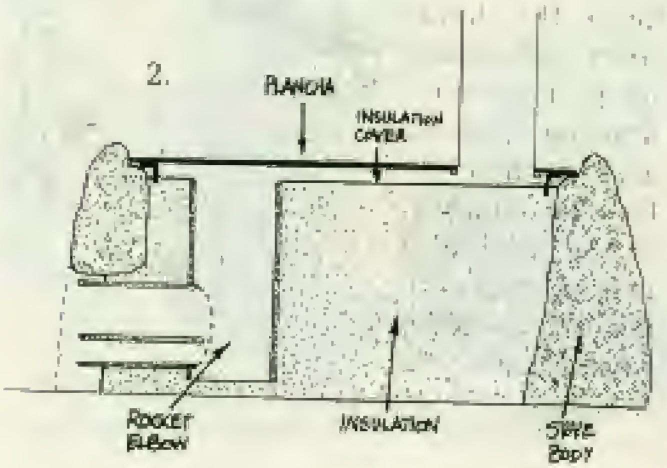
Dona Justa Stove type C

As more of the pot is directly exposed to heat, efficiencies rise. The griddle is supported on top of a box built from ordinary brick, Lorena, or any inexpensive material like adobe, etc. If the chimney is cement, it can be a part of the box, supported by four walls. The heavy chimney is placed behind a wall of brick that allows hot flue gases to flow unimpeded into the bottom of the chimney. See drawing 1.



1.

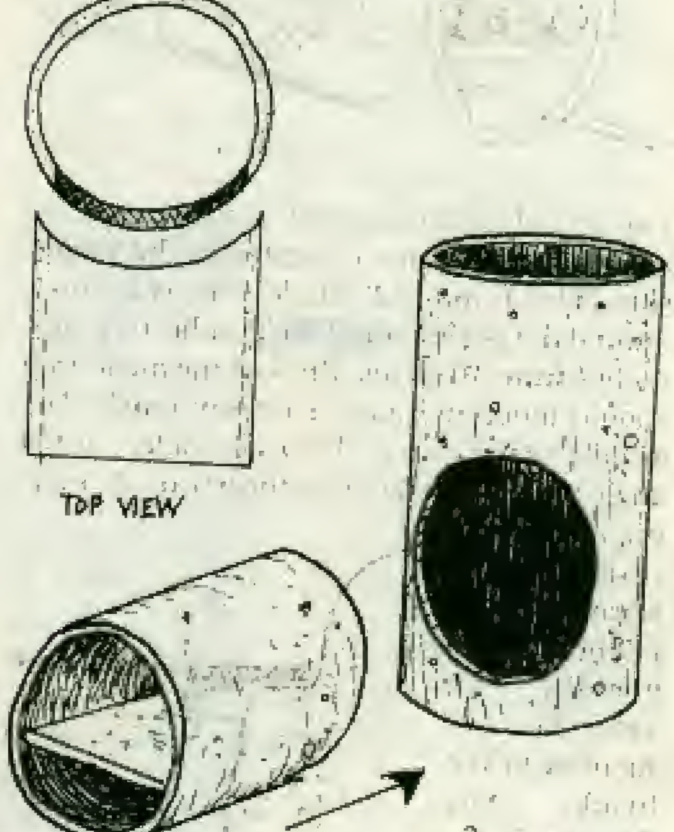
If the chimney is made from sheet metal it can rise directly out of a hole cut in the griddle. See drawing 2.



2.

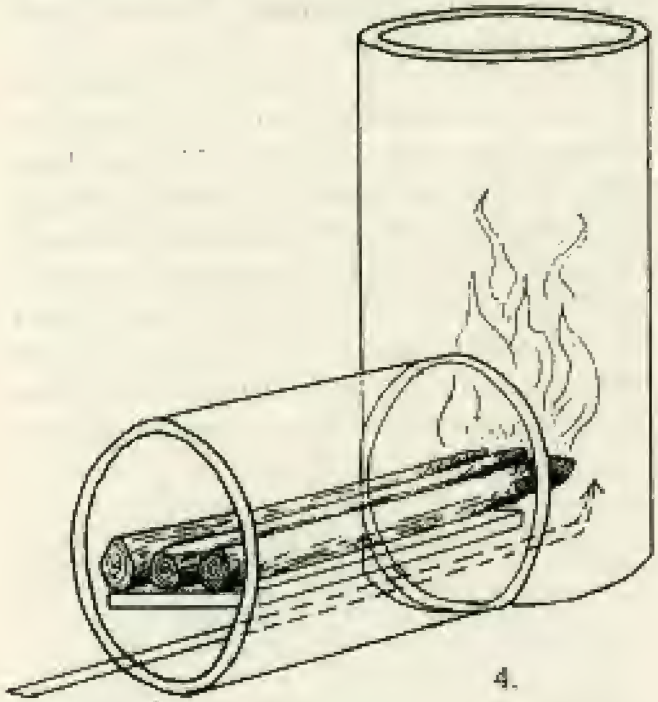
Brick and Earthen Stove Bodies

The Honduran stoves use a Rocket combustion chamber in the shape of an "L" made from a refractory ceramic which consists of horse manure, clay, sand, and tree gum. These cylindrical parts can also be made from heavy steel, black iron pipe, 430 stainless steel, or refractory cement. The combustion chamber fits into the mouth of the stove and the two parts should be made to join without large gaps. Insulation surrounds the combustion chamber, filling small gaps and preventing smoke from leaking. See drawing 3.



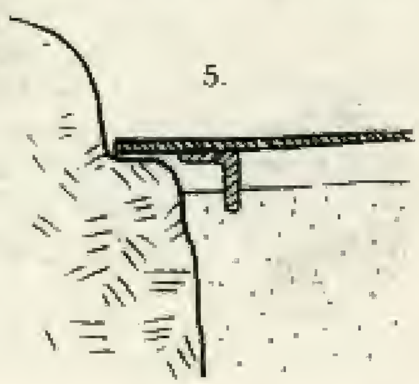
3.

The mouth of the combustion chamber contains a shelf, about one third up from the bottom of the cylinder. The purpose of this shelf is to assist proper feeding of wood into the fire. The sticks of wood make a grate formed by stick, air, stick, air, etc. The sticks, as they burn side by side, create a hot burn, assisting the combustion of smoke. See drawing 4.



4.

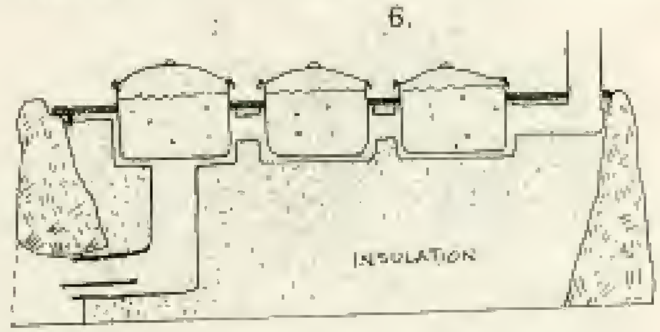
The 1/8"-thick steel griddle will warp unless angle iron is welded or bolted to the underside. The 1-and-1/2" angle iron is secured around the perimeter of the griddle, inset two inches from all edges. Ends of the angle iron should meet and join or closely touch. The griddle sits on top of the brick walls, but the angle iron submerges into the wood ash, making a seal that resists smoke entering the room. The griddle can also be cemented to the brick. See drawing 5.



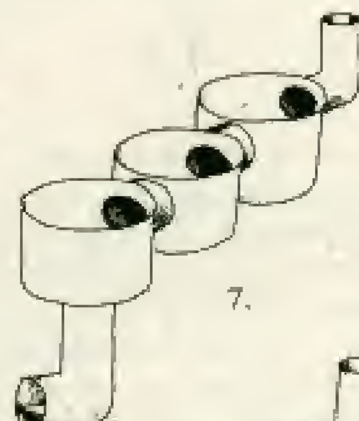
5.

Insulation fills up the stove, leaving a 3/4" gap under the griddle. The most natural and least expensive insulation is probably wood ash. If a sufficient quantity of wood ash is hard to find, a poorer insulator can fill most of the stove as long as 6" of wood ash surrounds the combustion chamber and lies under the griddle. Poorer insulators (which can also fill the entire stove, with less optimal results) include perlite, vermiculite, light pumice rock, dead coral, charcoal, and dry fluffy earth. See drawing 6.

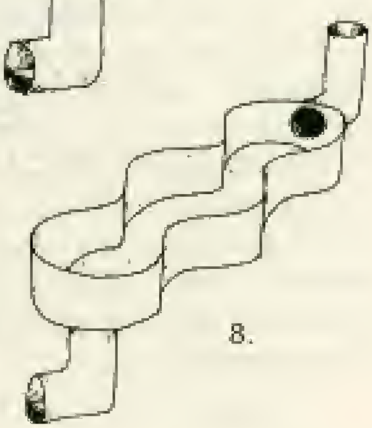
6.



Submerging the pots under the griddle can double the efficiency of heat transfer. We have done this in two ways. A.) Cut holes in the griddle into which the pots exactly fit. Use sheet metal to create a 1/4" gap all around the pots so that the heat is always in an insulated environment. You can either do a great job and keep the heat from contacting the griddle, as in drawing 7, or be a bit lazy and follow the contour of the pots in a more general fashion, as demonstrated in drawing 8.

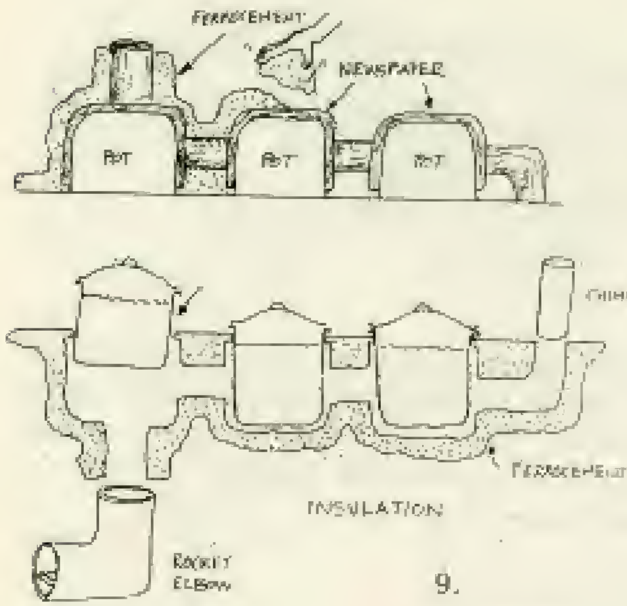


7.



8.

Method B, uses refractory cement. The cement is formed around the actual pots to be used. Wrap the bottom half of the pots in newspaper or other material. A gap of 1/4" will be created when cement is pressed around the male mold. Let cement directly touch the oiled pot so that a smoke-tight fitting is created near the top of the pot or just under the handles. Adding the mass to the stove does cut back on efficiency, but the refractory cement will greatly outlast the sheet metal used in the low-mass model. See drawing 9.

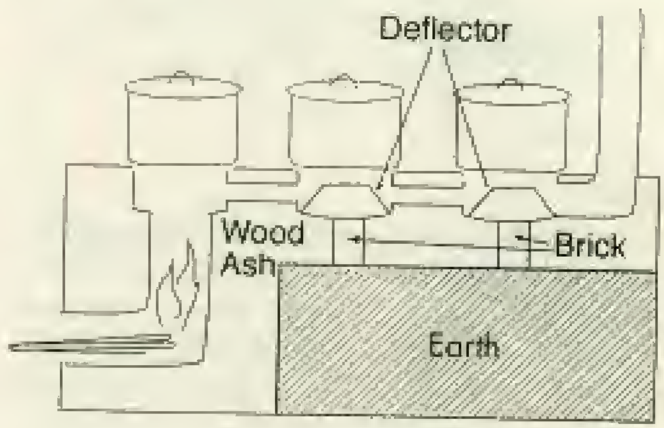


9.

There is always variation in an Appropriate Technology design. One village may insist that pots stay clean. A village fifty miles away may need greater fuel efficiency. As explained above, allowing heat (and soot) to directly touch pots increases efficiency. Pots can sit on top of three holes cut into the plancha. They block smoke from entering the room. This type of stove is more fuel-efficient than the closed-griddle Justa because the fire directly contacts the bottom of the pots. When the fire travels between pots it can be in insulated tubes and doesn't lose much heat. We want to get as much heat as possible into the pot and nowhere else!

The open-hole variation of the Dona Justa stove can be up to 30% efficient. The efficiency rises a little more when a fourth pot is exposed to the heat. A four-pot stove absorbs a bit more of the heat before it is wasted out of the chimney. But the little amount of remaining heat makes for a very low-powered fourth burner. The fourth burner is really only good for heating dish water, etc. In our experience, it is not powerful enough to cook food.

Another important design feature of this variation, the deflector, directs heat at the bottom of the pot. A piece of metal or ceramic sits in the burner and forces heat up to the pot, making sure that, unlike the Lorena, there is improved heat transfer. The deflector is shown in the following drawing. It sits inside the second and third burners. The deflector substantially raises the overall efficiency of the stove about 6%.



A More Efficient Dona Justa Variation

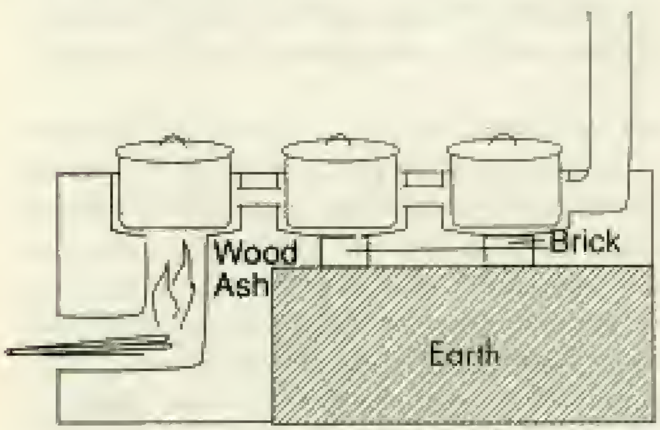
A 40%-efficient stove with chimney results from partially submerging the pots below the griddle. The heat from the fire is directed at each pot through a skirt around the pot's sides. Three pots are tightly fitted into holes cut in the plancha. If the holes are cut properly, smoke cannot escape into the kitchen.

A cement plancha can be formed around the pots, as well. Skirts surround the bottom and

sides of the pots, under the stovetop, forcing the heat to contact more of the pot. If the gap is optimal (in this case about 1/4") and the same cross-sectional area is maintained (to assure steady draft) as heat travels past the sides and bottoms of all three pots, this stove can reach efficiencies of 40%.

The efficiency of this stove is highest because the greatest amount of heat is striking the most surface area of the pots.

As in the previous stove, both combustion chamber and fire flow path are insulated with wood ash, perlite, vermiculite, or fluffy earth. The plancha is also thermally isolated from the heat by insulation.



The Most Efficient Dona Justa-Type Stove

These stoves, the Rocket and the Dona Justa, demonstrate more or less efficient ways to help create a reduced-smoke or smoke-free kitchen. The Rocket stove can be a useful option if, for economic or other reasons, a chimney is not going to be used. The stove with chimney removes the smoke and for that reason is always preferable. Although the griddle-type stove, and variations including sunken pots, have been built and used in the past, Larry has introduced several features that are novel and important:

1.) The Rocket elbow assists cleaner and more complete combustion.

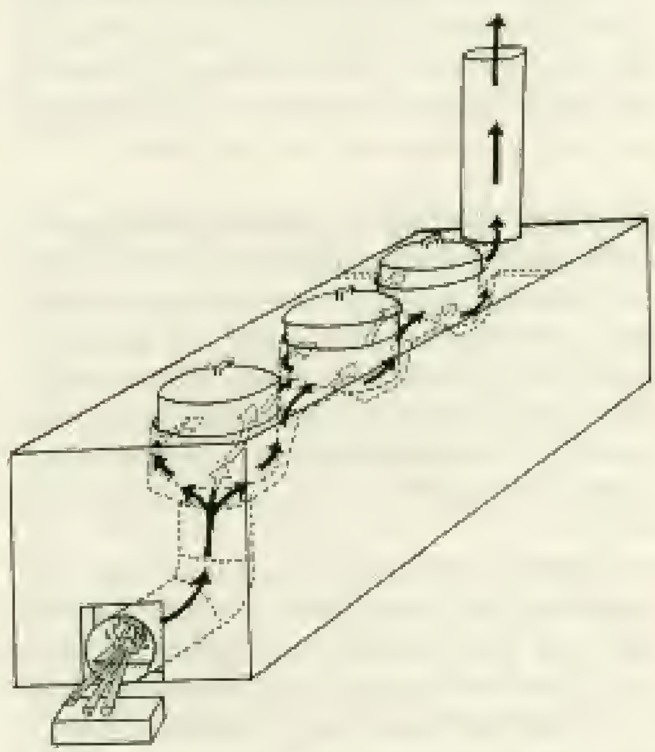
2.) The gap between the pot and skirt is smaller, forcing heat to rub against the pot.

3.) The entire heat flow path is insulated, lessening heat absorption into the stove body.

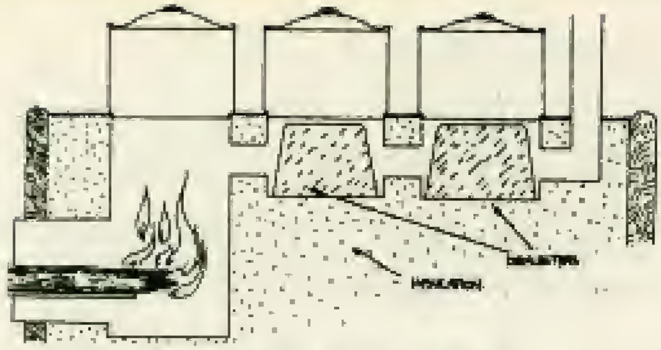
4.) A smaller, well-insulated combustion chamber allows the use of fewer sticks, since the fire does not tend to die out as easily.

Fuel Efficiency in Stoves

The draft created by the internal Rocket and external chimney makes it possible to force the heat through a narrow opening beneath the second and third pots, increasing the success of efforts aimed at heat transfer. Tall chimneys are a big help when sucking heat through a circuitous maze of heat exchangers inside a stove. For example, the deflector in the burners aims the heat at the pot. It can be used only when there is sufficient draft.



Air Flow in the Most Efficient Dona Justa-Type Stove



Deflectors Force Heat at the Pots

Forcing heat to contact the sides as well as the bottoms of the pots dramatically increases fuel efficiency. Increasing contact to the pot in the Dona Justa stove increases efficiency up to around 40%. It makes sense that to get a large percentage of the heat into the pots it is necessary to expose the maximum pot surface area to hot flue gases.

For better fuel efficiency, insulating the fire flow path is also essential. Imagine if the fire flow path were perfectly insulated so that no heat was lost or absorbed. By exposing sufficient pot surface area to hot flue gases we can be sure that a very high percentage of the heat cooks food. Theoretically, we need to leave only enough heat in the chimney to assure draft throughout the stove. In this perfect stove, efficiencies could be over 50%.

Something like 50% of the rest of the heat is lost because 1.) three normal-sized pots have insufficient surface area to absorb the released heat from the fire; 2.) keeping exit temperatures above 250 degrees F. to establish sufficient draft is inherently wasteful; and 3.) heat is also lost into the stove body, excess air cools the fire, combustion is never complete, etc.

The perfect stove would not lose heat into the stove body. It would be so well insulated that heat would not be lost by conduction, convection, or radiation. All of this captured heat would be forced to brush against as large a percentage as possible of the surface area of the pots, efficiently heating them up, until the exit temperatures from the chimney were very low. Almost all the heat would be in the pots, leaving only enough to continue the draft.

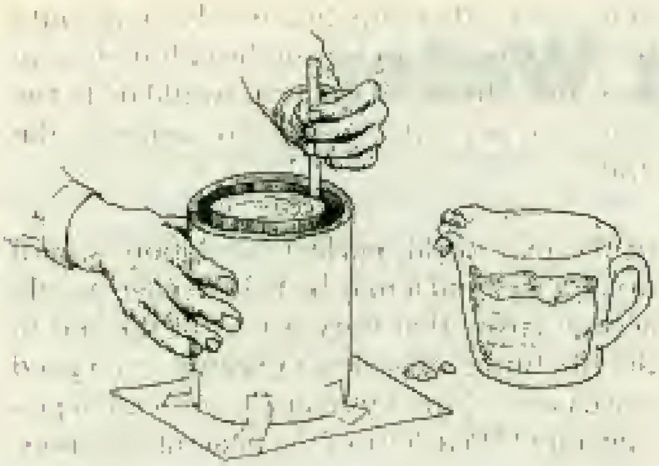
In the real world, perfect insulation is hard to come by. And it may be hard to have people accept stoves that bury a part of the pot in the fire tunnel. For these reasons, even good stoves with chimneys usually succeed in getting only 15% to 30% of the heat into the pots.

Using more pots to pull heat from the fire increases efficiencies. However, as mentioned above, more than three pots are hard to heat. The fourth pot will warm but it's not likely to boil. Of course, it's nice to heat wash water semi-automatically, and the fourth burner is perfect for low temperature jobs like these.

As mentioned, these stoves can be built with low-mass ceramic parts. A co-op in Honduras called Nueva Esperanza makes durable stove parts from sand, clay, horse manure, and tree gum. Cultures around the world have developed refractory clay mixtures that stand up to the heat of flame. Or the internal stove parts can be made from thick steel pipes, replaceable thinner steel, tin cans, 430 stainless steel (which holds up in stove use), etc.

There are also pourable refractory cements that do not degrade at normal stove temperatures. We find that parts made from this material are relatively cheap (20 dollars for a 50-pound sack), are easy to work with, and have a long life. We don't recommend reducing wall thickness to less than 1/2".

(Refractory cements are available from North American Refractories Company, 500 Halle Building, 1228 Euclid Ave., Cleveland, Ohio 44115. Phone: (216) 621-5200.)



Tamping Refractory Cement into the Mold

It is quite easy to make molds out of cardboard. Or you can use big pop bottles or found objects to act as molds. The refractory cement pours easily, but it's best to use a stick to make sure there are no air bubbles in the casting. Be careful not to breathe the dry mixture, as it contains silica. We find that the wet mixture is easier on the hands than regular cement, although it is still advisable to wear gloves.

The internal stove parts are surrounded by insulation, which can be wood ash, pumice rock, perlite, vermiculite, fluffy soil, etc. This combination makes for a highly insulated stove. The outer, durable box can be made from brick, Lorena, cement block, etc. The mass of the stove body is thermally isolated from the heat of the fire by the insulation.

If the internal parts are made from heavy amounts of Lorena mix, concrete, or simply mud and clay, then the overall efficiency of the stove will drop considerably due to absorption of heat into the mass. Even high-mass stoves, however, will benefit from many of the design patterns suggested in this chapter. The low-mass three-burner Justa made from tin cans averaged 33% efficiency. When we surrounded it with more than 75 pounds of concrete, the average efficiency dropped to 24%. Tin cans, however, do not last.

It is a good idea to design a stove to achieve as complete combustion as possible. Even though chimneys carry smoke out of the room, that is not a great solution if the smoke enters the neighbor's house through the open doors and windows. Designing for "complete combustion" always seems preferable.

To accomplish better combustion Larry insulates around the combustion chamber, uses a shelf in the fuel magazine, and includes a Rocket-style chimney above the combustion chamber. A hot, fierce fire is a clean fire.

Larry also does not include dampers in the chimney. If a decrease in air is needed it is better to regulate excess air through the opening into the combustion chamber. Using a damper is something like regulating air flow into the car's carburetor by partially blocking the tailpipe with a potato! It's far better to allow the proper amount of air into the carburetor initially. We want a small amount of hot air contacting the fire at high velocity. A small opening that aims air at the base of the fire will keep the fire burning fiercely. Partially blocking the chimney slows down the airflow, and is therefore detrimental to clean combustion.

The options and suggestions put forth in this booklet summarize a couple of decades of stove designing and testing. The general understanding of how stoves work has matured a lot since the early days of the 1970s. Hopefully these design patterns will come in handy if you need a wood-burning cooking stove! Any of the Justa models are easy to make and can serve as a primary source for cooking. Add an oven by building an insulated box around the chimney, on top of the plancha. For a hotter oven, change the chimney shape from cylindrical to rectangular and include as much chimney in the box as possible.

Heating Water

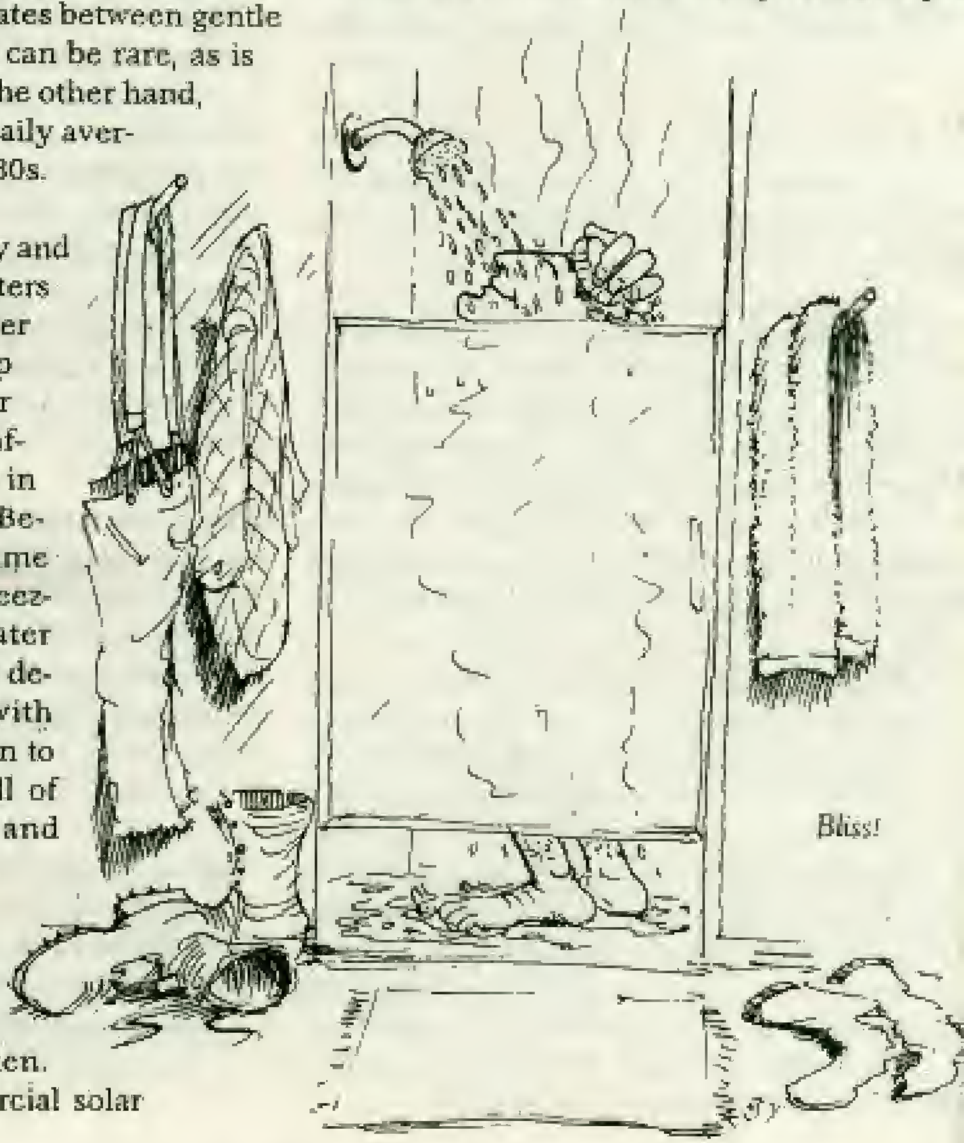
We have developed five simple and successful ways of heating water over the years. Three of the designs use combusted biomass to warm water. The fourth and fifth are solar water heaters. A combination of wood burning in the winter and direct solar water heating in the summer seems to suit our maritime climate.

Aprovecho is located in a wonderful part of the planet (44 degrees north latitude) in a long valley nestled between coastal hills and magnificent mountains, about 50 miles inland from the Pacific Ocean. During the winter our weather generally alternates between gentle rain and fog. Sun breaks can be rare, as is snow. Our summers, on the other hand, are dry and warm, with daily average temperatures in the 80s.

In this climate, even fancy and expensive solar water heaters receive very limited winter sunlight. It's sad to look up at thousand-dollar solar water heaters which day after day merely keep clean in the relentless drizzle. Because our winter nighttime temperatures dip below freezing, the solar water heater needs to be a pretty fancy design, one that is filled with anti-freeze or knows when to drain itself. Anything full of water tends to expand and crack.

Water expands as it freezes (most everything else shrinks in size!) and pipes can easily be broken. That's why most commercial solar water heaters don't directly heat water. Instead, a liquid, like antifreeze, is warmed up in the solar collector, and then the warmth is transferred inside the house to a tank of water. Directly heating water resulted in too many accidentally broken pipes.

Our water-heating efforts evolved at Aprovecho until wood warmed water in the winter and sun did the same in summer. This strategy evolved because wintertime solar water heaters mostly burst while remaining cold in the fog. We were cold and dirty and wanted nice warm baths! Using the sun to pre



Bliss!

heat water, that was then fully warmed by other means, was not judged worth all the expense and hassle. Stored solar energy, in the form of wood, could be used in the winter, and direct solar energy made lots of water scalding hot all summer long.

If you live in a continually sunny climate, solar-heated bath water is certainly the way to go. It's especially easy to accomplish in places where temperatures do not go below freezing. In Baja California Sur, Mexico, eight inches of water in a dark painted cistern without a glass cover was usually more than 100 degrees F. by late afternoon. An insulated cover provided hot water for the morning's dishes. Try simple solar first if you live in a sunny climate!

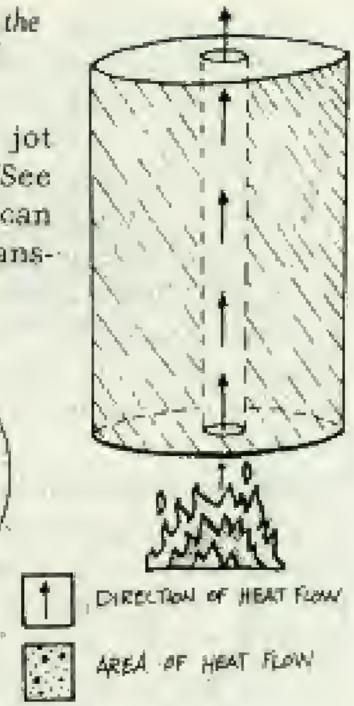
The Winiarski Batch Water Heater

In Mexico, outside of a lot of bathrooms, and for sale at fancy "Alternative Energy" stores in the US, you can find a Mexican-made wood-burning batch water heater. It's called a batch heater because you heat up a tankful of water at a time. The fire is located underneath the tank of water and the flame and hot flue gases shoot up the middle of the tank through a 3"-diameter chimney. The chimney is welded to be watertight. Heat from the flame warms the water in the tank, which is driven under pressure out of the top of the tank, to the nozzle that wets the lucky recipient.

When Larry looked at this design, he immediately realized that by simply changing how the chimney contacted the tank he could greatly improve the efficiency of heat transfer and heat the water using much less fuel. What do you think Larry did?

Please take a minute to contemplate solutions to this problem. The following illustration shows how the Mexican model works:

Right: Heat Shoots Up the Middle



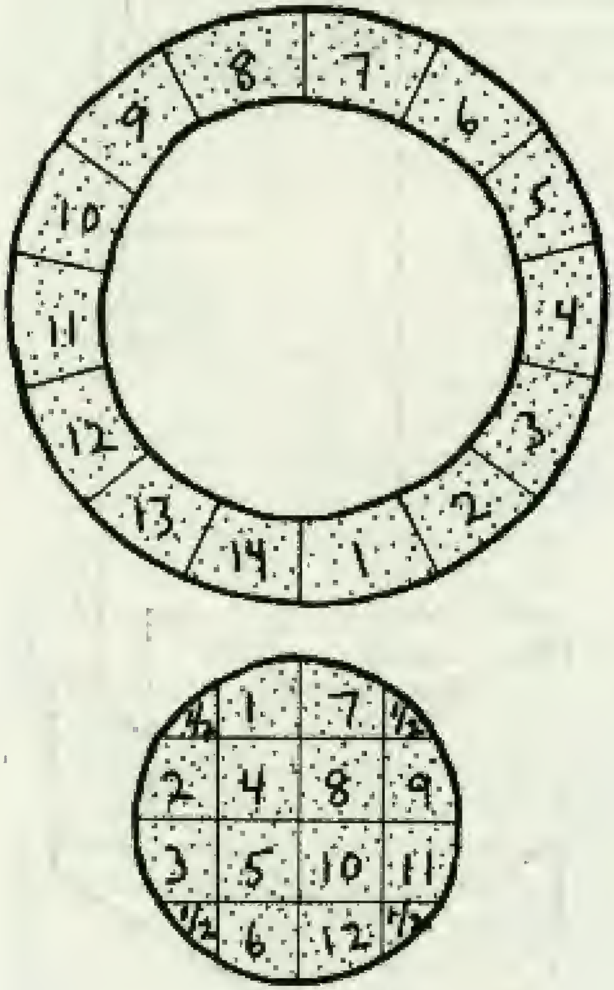
Please feel free to jot down your ideas. (See pages 45-48.) How can we increase heat transfer to the water?

Top View of the Water Heater

Larry realized that the area exposed to the water inside a 3"-diameter tube was pretty small. For efficient heat transfer you want as much water surface area as possible exposed to the heat created by the fire. To expose the most surface area, Larry put the chimney around the outside of the entire tank instead of inside it. This solution is reminiscent of his bread oven. Heat travels up a narrow gap, rubs against the water tank and efficiently heats up the water!

Right: Increasing the Exposed Surface Area

To make sure that the chimney created the same amount of draft Larry estimated the cross-sectional area inside the tube.

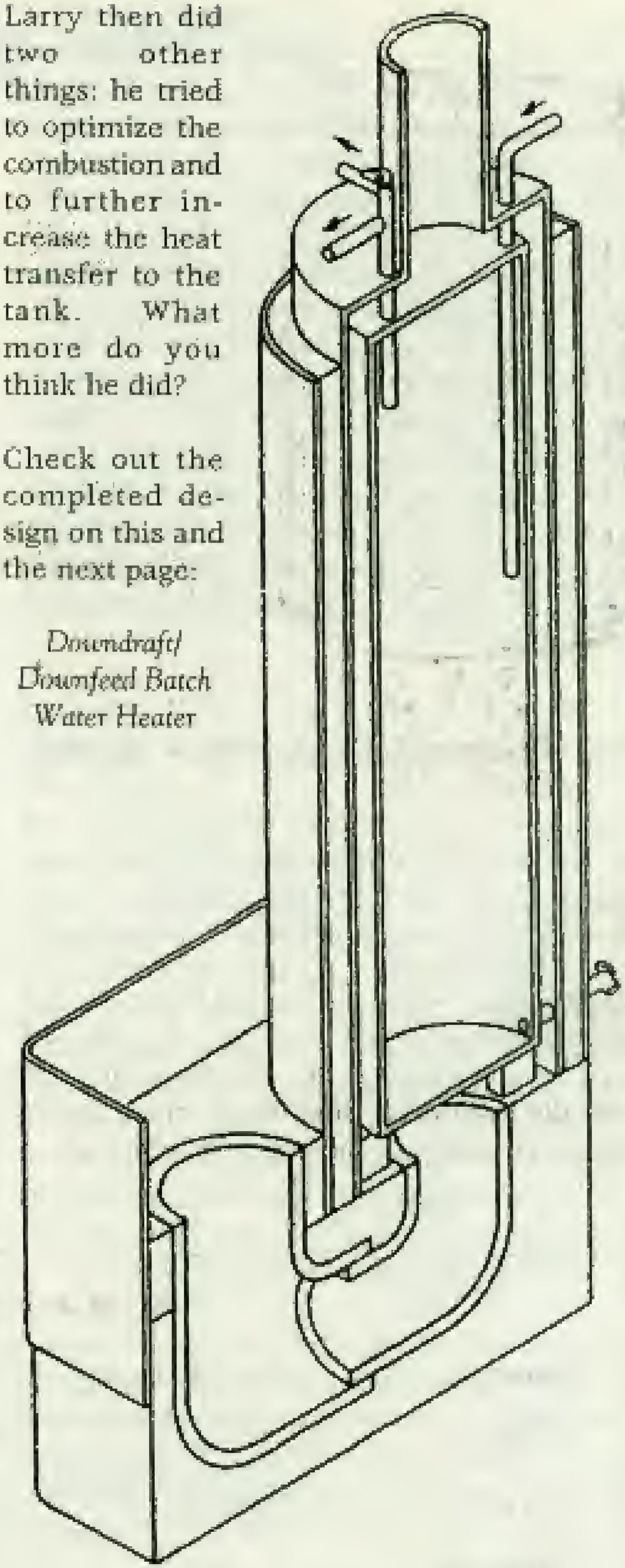


Same Cross-Sectional Area

Then he made sure that the gap between the tank and the new big chimney pipe created a gap with about the same cross-sectional area. Using the same cross-sectional area made the gap (called an annulus) between the two cylinders pretty small, so small that it might get clogged with creosote or ash. So, he compromised and made the gap 3/4", and lit an experimental fire underneath the tank with its exterior chimney. It worked great! The draft was swift and the water got hot quickly.

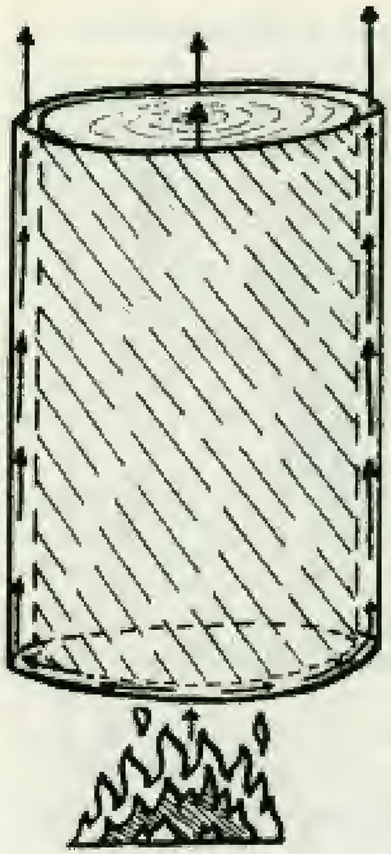
Larry then did two other things: he tried to optimize the combustion and to further increase the heat transfer to the tank. What more do you think he did?

Check out the completed design on this and the next page:



Downdraft/ Downfeed Batch Water Heater

Let's look first at the combustion and feed chamber. There is insulation surrounding the entire fire and fire flow path. The insulation

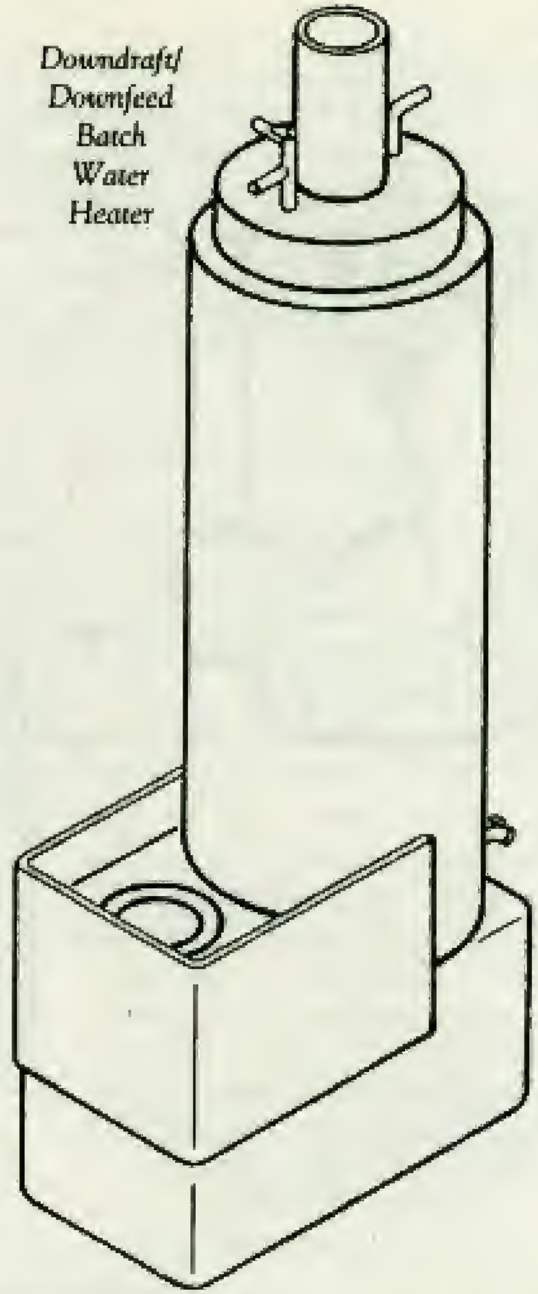


Downdraft/ Downfeed Batch Water Heater

keeps the fire hot for cleaner combustion and thermally isolates the stove body from the heat. Not much heat is lost uselessly into the stove body. Wood ash works well in stoves; it won't burn and is available wherever there are fires! As you can see below wood ash is comparable to asbestos and is usually free!

Notice that Larry chooses to use the downdraft/downfeed pattern for feeding the sticks into the combustion chamber. The sticks are presented to the fire vertically and burn at the bottom. The fire is swept horizontally toward the tank by the draft created by hot air rising in the oven and chimney.

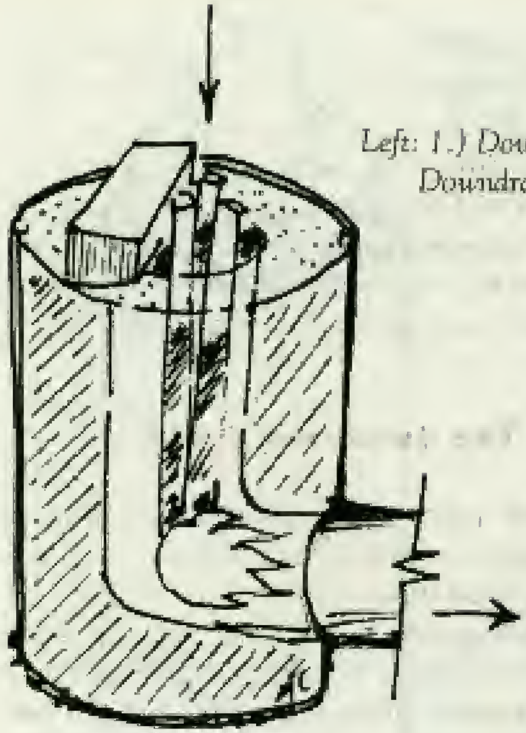
Downdraft/ Downfeed Batch Water Heater



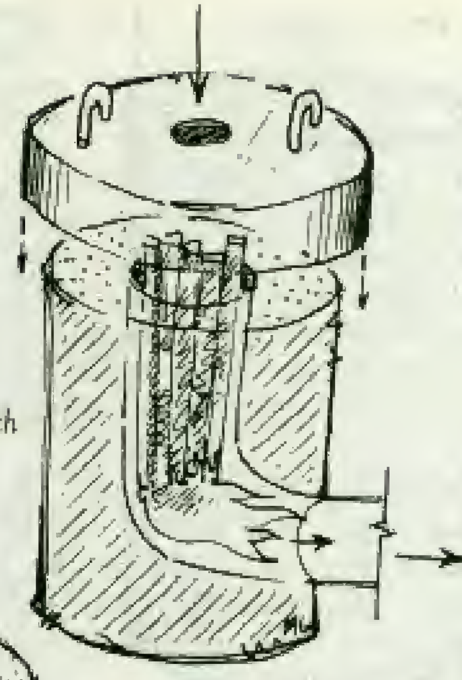
Wood Ash as Insulation

Material	Specific Heat*	Density**	Conductivity***
Asbestos	.20	36	.097
Wood ash	.20	40	.092

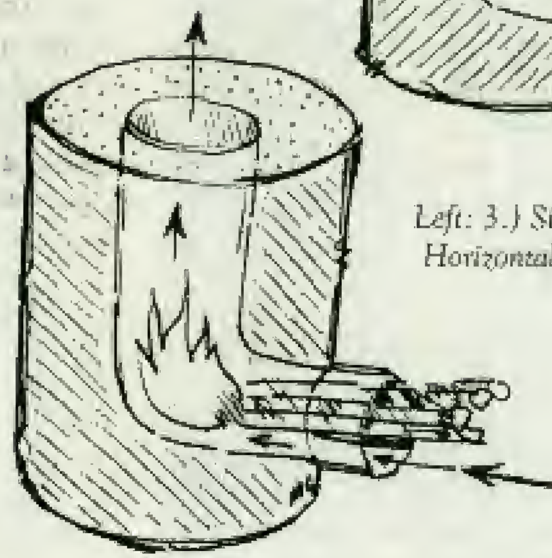
*Btu's to raise 1 lb. 1 degree F.
**lb./cubic feet
***Btu's per hour per square foot divided by depth (in feet)



Left: 1.) Downfeed/ Downdraft



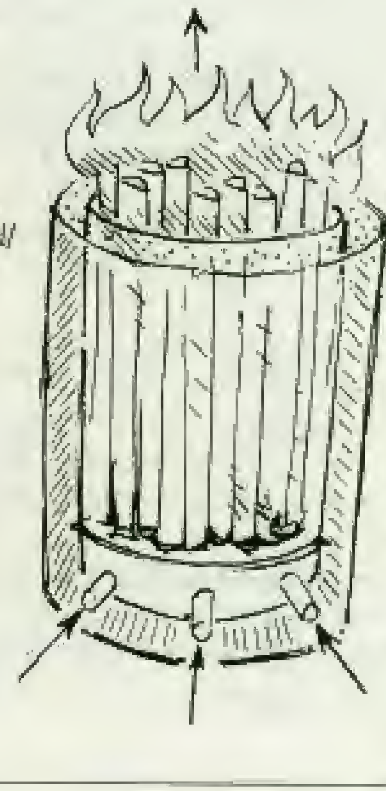
Right: 2.) Downfeed/ Downdraft with Cover



Left: 3.) Sidefeed/ Horizontal Draft

Downdraft describes how the air reaches the fire. This pattern provides the most preheating of air. These illustrations show how downdraft creates the best preheating of air. Air is sucked down towards the fire and is heated on the journey. This happens less in both sidefeed and topburning patterns.

This page: Patterns of Combustion
1.) Downfeed/Downdraft
2.) Downfeed/Downdraft with Cover
3.) Sidefeed/Horizontal Draft
4.) Batch Feed/Updraft



Right: 4.) Batch Feed/ Updraft

Hot air assists complete combustion. Allowing cold air into the combustion chamber can easily reduce temperatures. In a downdraft design, a brick or a stone blocks too much air from being pulled into the fire and helps the sticks to remain vertical. It's also easy to put a lid over the downdraft fuel magazine, allowing the right amount of air into the fire. You can put a door over the sidefeed entrance as well, but this option is often left unused or removed. (Although downfeed is theoretically preferable, most people like the convenience of sidefeed.)

First a design question for you:

We noticed something odd in our stove tests...

If you are measuring the amount of wood burned and comparing that to the temperature rise in a quantity of water, what is more efficient: heating a full pot of water or a half-full pot of water?

Think about the amount of the pot's surface area in contact with the water before answering.

It turns out that efficiencies rise as more of the pot is filled with water. As well, bigger pots are more efficient than smaller pots. A really big pot, like a big steel drum, has a considerable advantage over a smaller pot. It is inherently more efficient (if you need a lot of hot water or food).

That's why when testing stoves it is necessary to use a standard pot in all tests. Bigger pots are better heat exchangers.

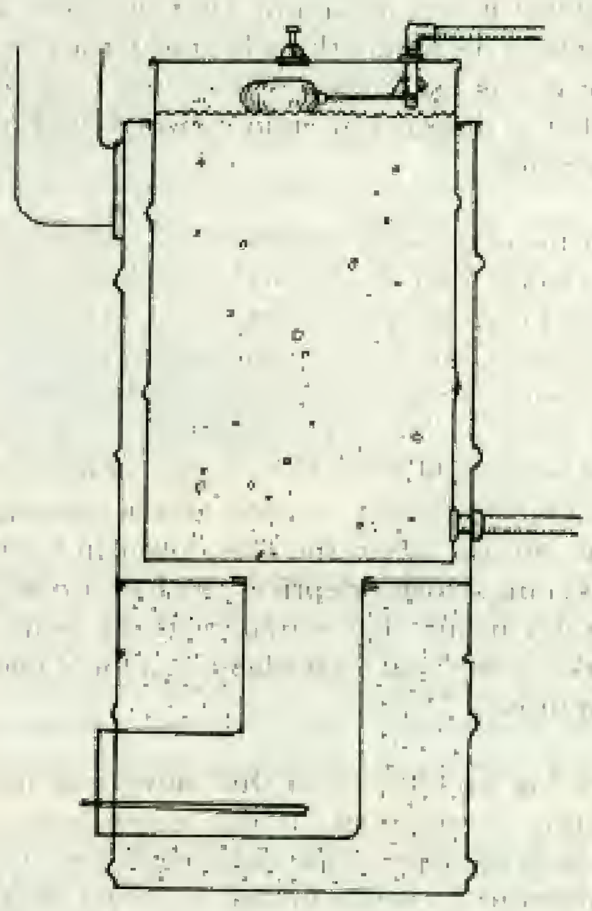
What I love about this design is how cleverly Larry incorporates a sealed skirt around a 33-gallon "pot." To make this 35%-efficient stove, you need to do the following:

Take the resealable lid off of a 55-gallon drum. Place the 33-gallon drum in the middle of the lid and scribe the circle. Cut away the interior of the circle BUT leave 2"-long tabs that will fit tightly against the 55-gallon drum. (See diagram.) If you're careful, the lid will make an almost airtight fit. Stove cement can seal the connection if necessary.

The lid stays with the smaller drum when it is removed from within the larger drum for cleaning. Hot flue gases travel up in the annulus between the two drums and exit out of a 6"-diameter chimney pipe located on the opposite side of the fire.

You will notice that it is possible to locate th firebox dug in the ground. Tiles or stone make the combustion chamber that is bac filled with wood ash or pumice rock or oth natural insulators such as perlite or vermic lite. Bricks or stones hold up the 33-gallo drum, which will be quite heavy if filled wit water. (One gallon of water weighs about 8 pounds.)

Larry does not show it in this sketch, but f greater efficiency one could insulate aroun the outside of the 55-gallon drum in the sam manner as with the bread ovens.



Sudanese Gravity Water Heater

Why not take a minute to think up a few way to design your own water heater? (See page 45-48.) What pattern would you choose fo the combustion chamber? Where should th

Insulating the Heat Flow Path

Insulating the heat flow path includes insulating around the water tank and chimney. A third metal cylinder, obtained from a larger water heater, surrounds both interior cylinders. The space between the second and third cylinder is filled with insulation. Any kind of insulation (that will not burn) will work but it is often easy and compelling to use aluminum foil in these types of applications.

Aluminum foil will block the radiation (or infrared heat) and direct it back at the water. But aluminum foil is also very conductive. Where aluminum foil touches metals, or itself, heat will instantly pass through it. A solid bridge of foil between two cylinders will shoot heat through to the outside. The trick with aluminum foil is to make up a blanket of four or five layers of foil, air, foil, air, foil, air, etc. The thin layer of air between each sheet creates the insulative effect while the layers of shiny foil almost completely block radiation heat flow. Although this sounds difficult it seems to work well in practice. A spiral of foil can be wonderfully effective insulation, easy and cheap.

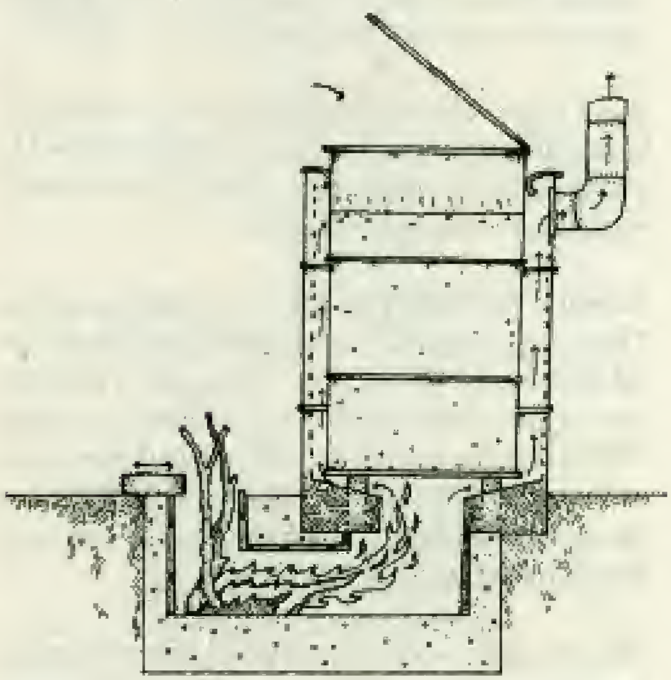
Foil will degrade if exposed to high temperatures. So aluminum foil will not last around a combustion chamber, but it will do great around a space where working temperatures tend to stay below 500 degrees F. Foil lasts almost forever around a baking oven, for example.

The batch heater used a forty-gallon tank from an electric water heater. The sheet metal for the exterior chimney came from its nice white cover. The gap between the two even happened to be 3/4". Perfect! Small bricks hold the tank up above the fire. Of all the wood-fired heaters we have used this is by far the preferred model. It is easy to use and almost free to make in the US, where old water heaters are trash.

At Aprovecho, our best model lasted through many daily showers for five years before the tank burned through. It used little wood, and heated 40 gallons of water up to bathing temperatures in less than 30 minutes. Keeping the fire going as people are bathing makes a never-ending source of hot water available. This design is highly recommended!

The Sudanese Stove

This stove represents perhaps the simplest way to heat a large quantity of water (or food) using nothing more than two steel drums, a 33- and a 55-gallon drum. And, in our tests, it outperformed the regular smaller Rocket cooking stoves. Larry designed it for the Red Cross who needed inexpensive large stoves to feed refugees in the Sudan.



The Sudanese Stove

exit tube be placed—near the top or bottom? I'm sure that your design will be better suited to your life than ours is! What materials around your place could be changed into a stove?

An Instantaneous, On-Demand Wood-Fired Water Heater

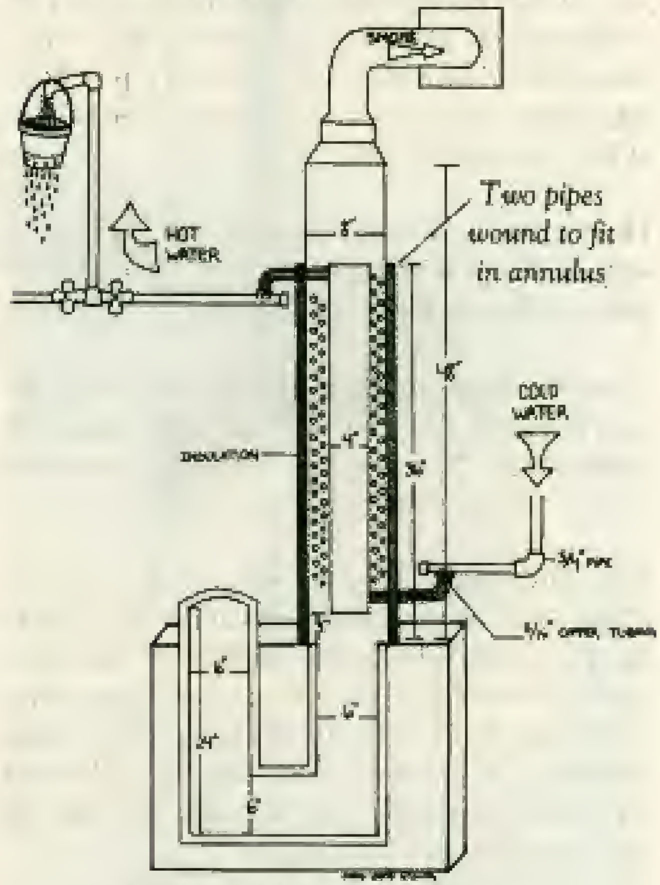
We broke down one long winter ago, in the early '90s, and installed a donated Paloma on-demand instantaneous propane-fired water heater. It had cost 600 dollars but was too small for the restaurant's dirty dishes. So we received it as a donation. After one year of watching the lovely thing heat water just before it was used, the students and I got together to design and build its wood-fired replacement.

Like too many of the prototypes that we build, this wood-fired on-demand water heater required too much tinkering, more than most of us would really want to do. But, when all systems were "go," the stove made beautifully hot water, at a constant temperature. Interns and staff could bathe luxuriously, content in the knowledge that no tank was being emptied. No one down the line, towel in hand, was being selfishly deprived. We had also built a water heater that worked without using a tank—something unavailable in a lot of poor countries.

The big problem with this stove was that people would turn off the water flowing through the pipes before dousing the fire. The explosions as water turned to steam either blew the safety valve or tore apart plastic pipe. This made for exciting bathing! There's nothing like a good explosion in the shower stall, while you're nude and wet, to clear the mental haze of comfort and naive relaxation.

A Paloma water heater, you see, only lights the fire after water is running through the pipe. It also will only light the fire, automatically, if more than 1.5 gallons per minute are flowing through the heating chamber. Our little wonder wasn't nearly so smart. Its safe use depended on human wisdom, which is in as short a supply at Aprovecho as elsewhere.

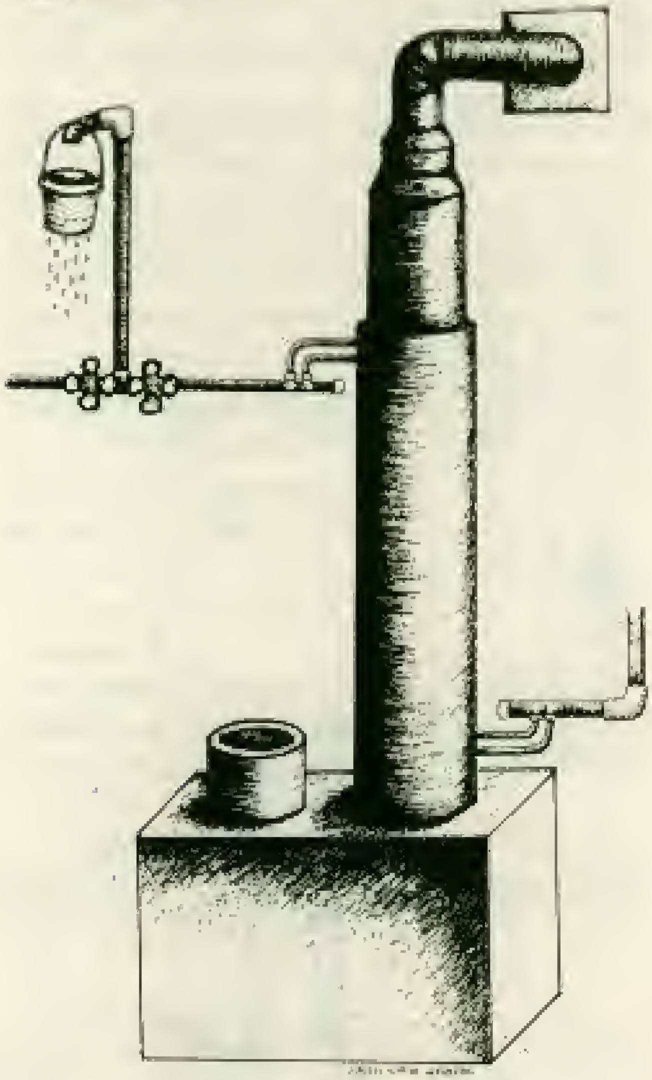
In this manual design, people had to be smart enough to regulate fire and flow. Generally, we found that this very simple stove worked for those of us who loved it as our own creation. It was a cute little monster. But, like a lot of the less-than-perfect A.T. devices, our bomb was scorned and derided by the wider Aprovecho community, who were not so glad to end a shower with submarine-like disasters.



On-Demand Wood Water Heater

The design is included here because there are many places in the world where it is impossible for regular folks to obtain a water tank. If tanks are not to be found, it is possible to

create a lively substitute that you can probably design to be perfectly safe! But our sage advice is that heating a batch of water is probably inherently safer than trying for on-demand service.



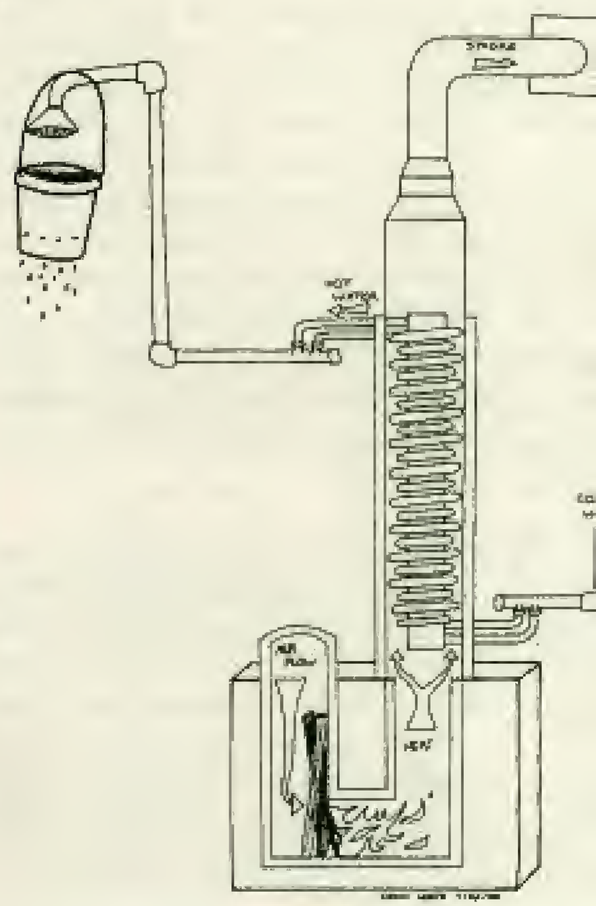
Seems Simple Enough

The great attraction of instantaneous designs is the use of pipes or copper tubing. This one had 40' of 1/2" copper tubing. Using a moderate fire, the water temperature rose an average of 65 degrees F. at two gallons per minute flow. Bath water is usually around 105 degrees F., so we needed to add a bit of cold water to the mix for comfort.

As you can see, the copper tube was cut into two 20' lengths and forged into two concentric spirals. We wanted to make the hot fl gases bounce between the pipes so that t heat was "rubbing" the tubing, not flowing pa it. What we wanted was something like closely packed pinball game where the b (the heat) constantly ricocheted between t cushions (the tubing).

The design neatly divides itself into combu tion and heat-exchange categories. The co bustion area uses Larry's preferr downdraft/downfeed arrangement. Insul tion surrounds the walls of the combusti chamber, which were made from a 8"-dia eter steel chimney pipe. Two straight sectio and two elbows easily slipped together cre ing a sleeve that lasted for about two years

Remember when making downfeed syster that the feed tube should be as low as po sible.



Downfeed Pattern in Instantaneous Water Heate

If the feed tube is too high it can function as a chimney and encourage backdrafting. A cover with an air hole cut in it can close off the top of the feed tube. This greatly assists hot burns. Covering most of the big opening gives immediate proof that cold room air cools both combustion and oven temperatures.

The hole in the cover can usually be about 2" in diameter. Keeping unnecessary cold air from the fire is very helpful. Temperatures in the heat exchanger will rise by about 75 degrees F. when the cover is in place. Make sure that the air hole is large enough (visually inspect the fire through the hole) to encourage rapid, fierce combustion.

But be careful when removing the cover. If the feed tube is filled with smoke and the cover is rapidly removed, it's quite possible to ignite the smoke trapped in the feed tube. This explosion can rush up the tube and cover furniture with ash, a dark reminder of the power hidden in uncombusted fuel (smoke)!

For this reason we generally do not have interns completely cover the feed tube. A brick does nicely to hold sticks in a vertical position and regulate the airflow.

The neat trick in this design, which assists efficient heat transfer, is to have the tubing contained within the annulus, between the 8"-diameter outer stove pipe and a 4"-diameter stove pipe which is closed off on the bottom and top. The only function of the inner chimney pipe is to divert the heat. Without it, the heat would flow up the middle of the flue and much less heat would end up in the water.

The last part of this system is the bucket that acts as a safety reservoir. I like the bucket a lot. To me it symbolizes the simplicity of a good A.T. adaptation.

We were bothered by unexpected spurts of too hot or too cold water raining out of the nozzle. A nameless intern punched holes in the sides of a plastic bucket, three inches up from the bottom of the bucket, and hung it below the shower nozzle. The holes were big enough to drain water faster than it filled the bucket. So, the water had a chance to mix a bit in a small reservoir first before contacting the helpless human below. In this simple way, the water temperature was moderated and bathers became more secure. Love that simple solution!

A Solar Water Heater

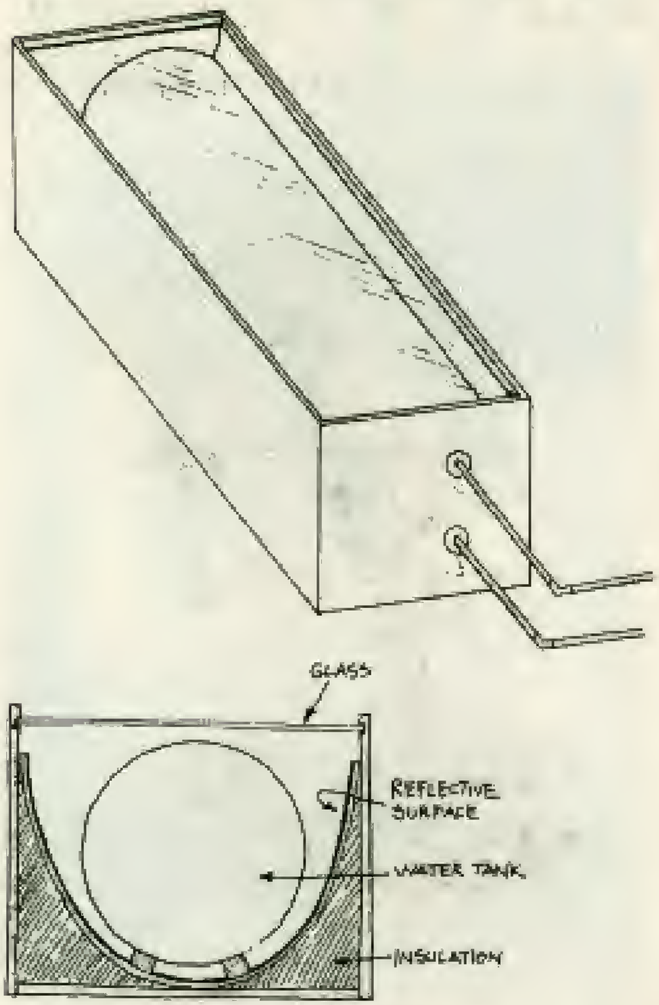
I'm not sure how old Aprovecho's batch solar water heater is; I do know that it's more than ten years old, predating my arrival. Since the

Batch Solar Water Heater

thing probably cost ten bucks to make, I would say that we have received better than fair service.

Heating bath water can be pretty efficient because the water doesn't have to get too hot. On a sunny summer day, the air temperature averages 80 degrees F. or more. Bath water needs to be only around 100 degrees F. The hot water in our batch heater gets to a maximum of 130 degrees F. The slight difference in temperatures (the Delta T) helps to reduce loss through the glass. A solar oven at 300 degrees F. is very much hotter than the outside air and losses are greatly increased.

To create an efficient solar water heater it's better to get more water to 100 degrees F. than



Batch Solar Water Heating Works!

to heat a smaller amount of water up to
130 or 140 degrees. It's best to size the t
so that temperatures do not exceed 100
grees F. by a great margin. At Aprovecho c
ing our warm summers this translates t
40-gallon tank. At the end of the day the
ter is hot enough for comfortable bathing,
not so hot that more heat escapes through
glass cover of the solar water heater.

Farrington Daniels must be a very likely c
didate for father of appropriate technology
it is accepted that Maria Telkes was mot
and E.F. Schumacher the high priest. In
wonderful book, *Direct Use of the Sun's Ene*
Daniels describes how 58% efficiency
obtained when the difference between in
and outlet temperatures in a solar wa
heater was 60 degrees F. Efficiency fell to 3
when the difference rose to 100 degrees
little difference in the Delta T really affe
efficiencies.

There are four design principles that res
in a good batch solar water heater:

1.) Large temperature differences (large Delta
create rapid loss of heat.

That's good in heating stoves but bad in a
lar water heater. We want to increase
amount of water in the tank until it gets
around 100 degrees F., but not much hot
by day's end. We want a small Delta T.

2.) Reduce losses from the solar water heater
all possible ways.

Insulate inside the box. Use double panes
glass as a transparent cover.

3.) Increase insolation.

Add north and south reflectors to the box. E
and west reflectors shade the glass. Positi
the box so that it is perpendicular to the su

Absorptivity Table

(The fraction of sunlight that is absorbed and then emitted as infrared heat.)

White, smooth surface	0.25 to 0.40
Grey to dark grey	0.40 to 0.50
Green, red, and brown	0.50 to 0.70
Dark brown to blue	0.70 to 0.80
Dark blue to black	0.80 to 0.90

Handbook of Air Conditioning and Heating, 1965

average position above the horizon. Also include reflectors inside the box to aim sunlight at the sides of the tank.

4.) Most importantly, increase as much as possible the ratio of sun-exposed surface area to water volume.

A cylinder full of water has a poor surface-area-to-volume ratio. A flat rectangular box will heat up water more efficiently. Unfortunately, tanks are easier to find. Shallow boxes are not very hard to make, however!

The batch heater is made with the 40-gallon tank from an old electric water heater. It was stripped of the outer cover and painted flat black. Flat black surfaces will absorb and then emit as infrared heat about 90% of the incoming sunlight. Lighter colors like green and blue absorb only 60% to 70% of sunlight. White paint, especially when shiny, reflects up to 90%, absorbing only 10% of the sun's rays.

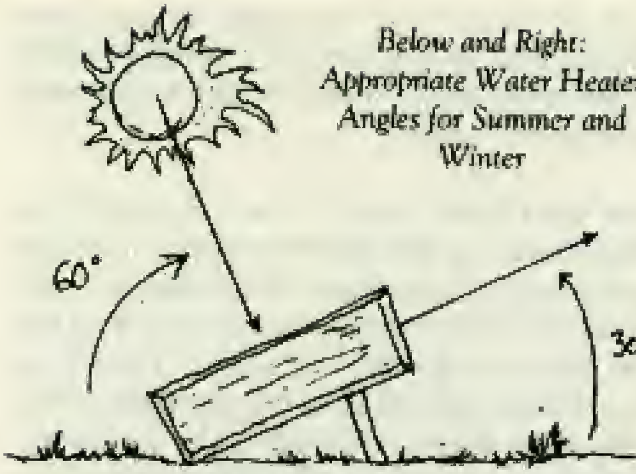
Some frog eggs are black on one side and white on the other side. If the egg is cold it rotates to expose the black side to the sun. If it is too hot it turns the white side towards the sun. By rolling around, the egg controls its internal temperature just like a great little solar water heater.

Our solar water heater is not so fancy. Humans made it, after all! It is just a used hot water tank, painted black, sitting inside a plywood box with a glass cover. The back of the flat black tank rests on top of a piece of Styrofoam, centering it in the rectangular box. Styrofoam doesn't conduct much heat away from the tank. If the tank were supported by metal this would create a conductive bridge, through which heat would be lost.

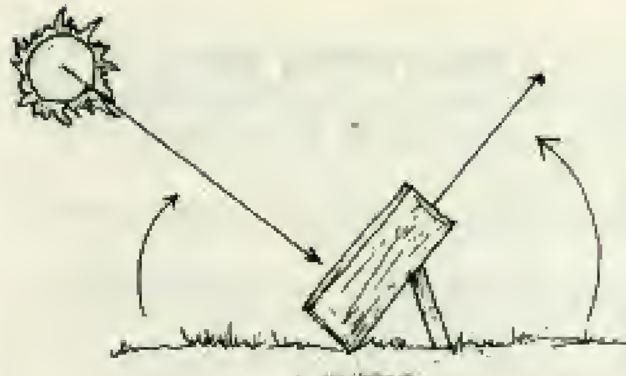
The shiny sides of the box, made from sheet insulation, are angled so that sunlight hitting the sides is reflected onto the black tank. The box is caulked and is relatively airtight. Hot water is taken out from the top of the tank and cold water fills in from the bottom.

Nature: The Best Design

Below and Right: Appropriate Water Heater Angles for Summer and Winter



SUMMER



WINTER

Because we had it around, we settled for one sheet of glass to cover the box. In our climate the water gets hot enough without the added expense of double-paned glass. The air gap between two sheets of glass greatly increases the insulative value of the glass. Remember that a single sheet of glass has almost no resistance (R) to the passage of heat.

An inch of wood is equal to about 1 R. A pane of glass is about .3 R. One-inch-thick sheet insulation is about 7 R. The new, argon-filled windows in the straw bale dormitory at Aprovecho are around 4 R. Packed earth has an R-value of about .25 per inch.

In a cold climate, double panes are necessary. At night, it's very helpful to cover the glass with insulation. The reflectors can be added to the top and bottom of the box so that their shadows never touch the glass. Reflectors on the side of the box cannot be used, because they would block sunlight in the morning and evening. The reflectors increase the square footage of incoming solar energy so the designer can use a bigger tank.

The box and tank are aimed at the average position of the sun. That's easier for us since we are only concerned with summer sun angles. If the water heater is to be used all year long it's necessary to make the box adjustable. Our latitude is 44 degrees north. Le do the simple math to figure out the best ang for our batch solar water heater.

Our latitude, 44 degrees, subtracted from 9 degrees is 46 degrees. 46 degrees plus 23-an 1/2 degrees (which is the earth's declinatio is 69-and-1/2 degrees. That's the highest th the sun reaches above the horizon in sur mertime.

44 degrees subtracted from 90 degrees is 4 degrees. 46 degrees minus 23-and-1/2 degre (again, the earth's declination) is 22-and-1 degrees. That's the lowest the sun reach above the horizon in the dead of winter.

Since we use the solar water heater only summer, we aimed the box so that its wi dow would be perpendicular to the summ average sun position, which is somewhe around 60 degrees above the horizon. Th meant that the box was inclined 30 degre from the horizontal to intercept the mo amount of direct sunlight. (90 degrees, a pe pendicular or right angle, minus 60 degree the angle of the sun, equals 30 degrees, th inclination of the top of the box.)

Luckily, close is good enough. Glass is ver transparent and we don't start losing a lot energy by reflection until the sunlight is at sharp angle to the glass. And as long as th box is aimed pretty close to the average dail sun above the horizon, losses are negligibl

You don't start losing appreciable square footage of sunlight until the box is very badly aimed. There's usually less than a 10% drop in efficiency even if the collector is pointed 45 degrees away from true south! (*Environmental Building News*, July/August, 1999.)

The tank is plumbed under pressure. When hot water is withdrawn, cold pressurized water flows into the tank, pushing the hot water onto the bather. In Mexico, lots of people fill black tanks on their roofs in the morning. By evening, they have a tank full of hot water, which makes a shower by gravity.

How much hot water can we make?

The box is 4' by 8'. That makes 32 square feet of intercepted sunlight. The interior reflectors direct almost all of the sunlight to the tank. The 5 hours around noon contain most of the daily input of heat energy. If we have 5 hours of strong sunlight during an average summer day, and if the average number of Btu's per square foot per hour is 200, then we calculate as follows:

- 5 hours/day x 200 Btu's(square foot)(hour) = 1,000 Btu's/square foot per day. (This is another good rule of thumb number!)

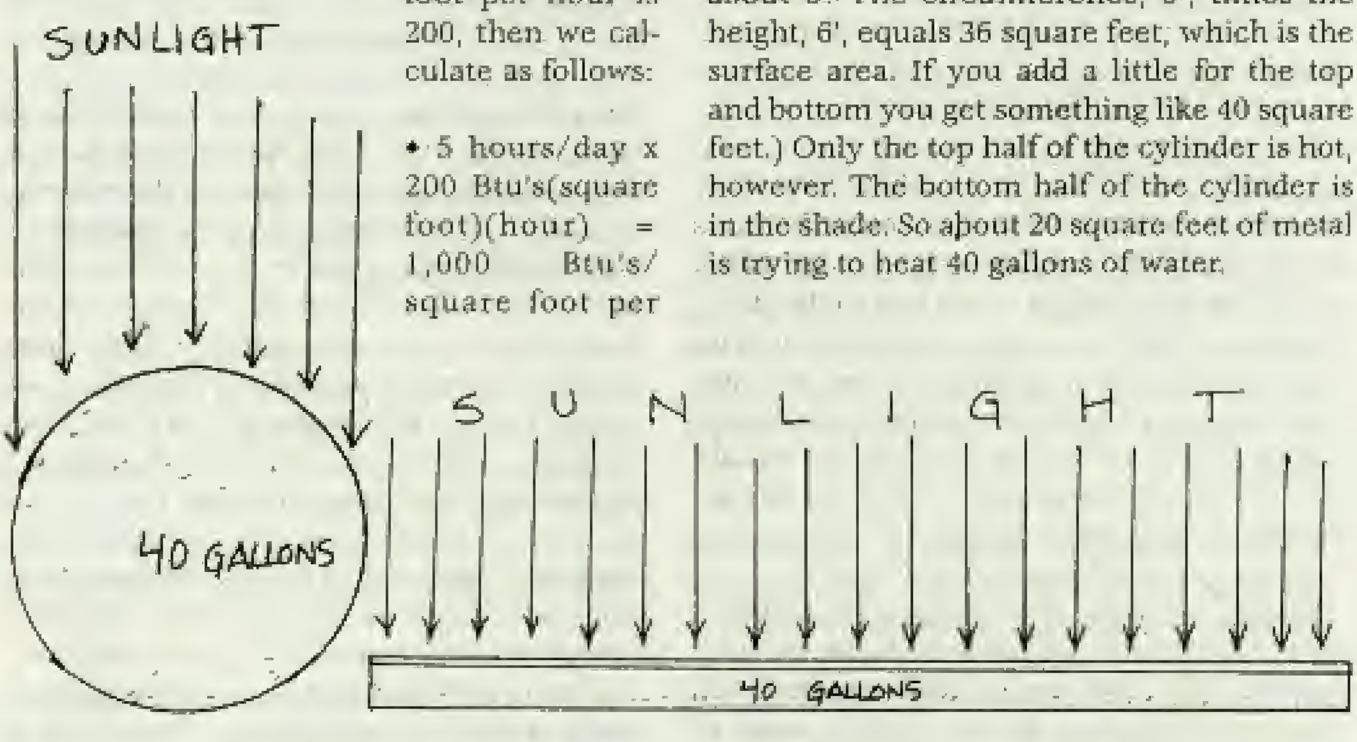
- 1,000 Btu's(square foot)(day) x 32 square feet = 32,000 total Btu's per day.

So something like 32,000 Btu's of energy hit the top and sides of the water tank.

Now, here's the big question: what percentage of the total Btu's actually makes it into the water by day's end?

The Delta T is low so we're not losing heat very rapidly through the glass although the R value is negligible. What hurts this design is that there isn't an optimized amount of hot surface area passing heat to the water. The optimal arrangement would have the most amount of hot metal touching as much of the 40 gallons as possible.

A 6'-long cylinder 2' in diameter has about 40 square feet of surface area. (The diameter, 2', times pi (3.14), equals the circumference, about 6'. The circumference, 6', times the height, 6', equals 36 square feet, which is the surface area. If you add a little for the top and bottom you get something like 40 square feet.) Only the top half of the cylinder is hot, however. The bottom half of the cylinder is in the shade. So about 20 square feet of metal is trying to heat 40 gallons of water.



Same Amount of Water but Greater Exposed Surface Area = Hotter Water

There is about one-half square foot of sun-exposed surface area per gallon in the water tank. A good collector has to have a higher surface-area-to-volume ratio. So due to a limited effectiveness in heat transfer ability, our batch heater will be only moderately efficient.

Great solar water heaters can be 70% efficient. They achieve these incredibly high efficiencies by insulating the glass cover (sometimes even using a vacuum, the best insulator), by optimizing the surface-area-to-water volume ratio, and by keeping water temperatures low. As a rule of thumb a simple cylindrical batch water heater will probably be around 30% to 40% efficient, give or take a bit.

We go back to our equation:

First, we'll assume that something like 40% of 32,000 Btu's make it into our 40 gallons of water.

Since it's best to underestimate performance we'll simplify and round down to 12,000 Btu's getting into the water.

Water weighs about 8.3 pounds per gallon.

• 8.3 pounds/gallon x 40 gallons = 332 pounds.

One Btu heats a pound of water one degree F., so our 12,000 Btu's would allow us to heat 12,000 pounds of water one degree F., or 1200 pounds of water 10 degrees F., or 120 pounds 100 degrees F., etc. With 332 pounds of water, we find that:

• 12,000 Btu's x (1 degree F. temperature rise)(1 pound of water)/Btu + 332 pounds of water = 36 degrees F. temperature rise.

So, if the water starts at 60 degrees F., we end up around 96 degrees F., which is nice for summer bathing. Maybe four people can wash both feet and hair every afternoon. If eve[...]
body wants to shower everyday at Aprovec[...]
we need to make six of these solar batches
make bigger designs.

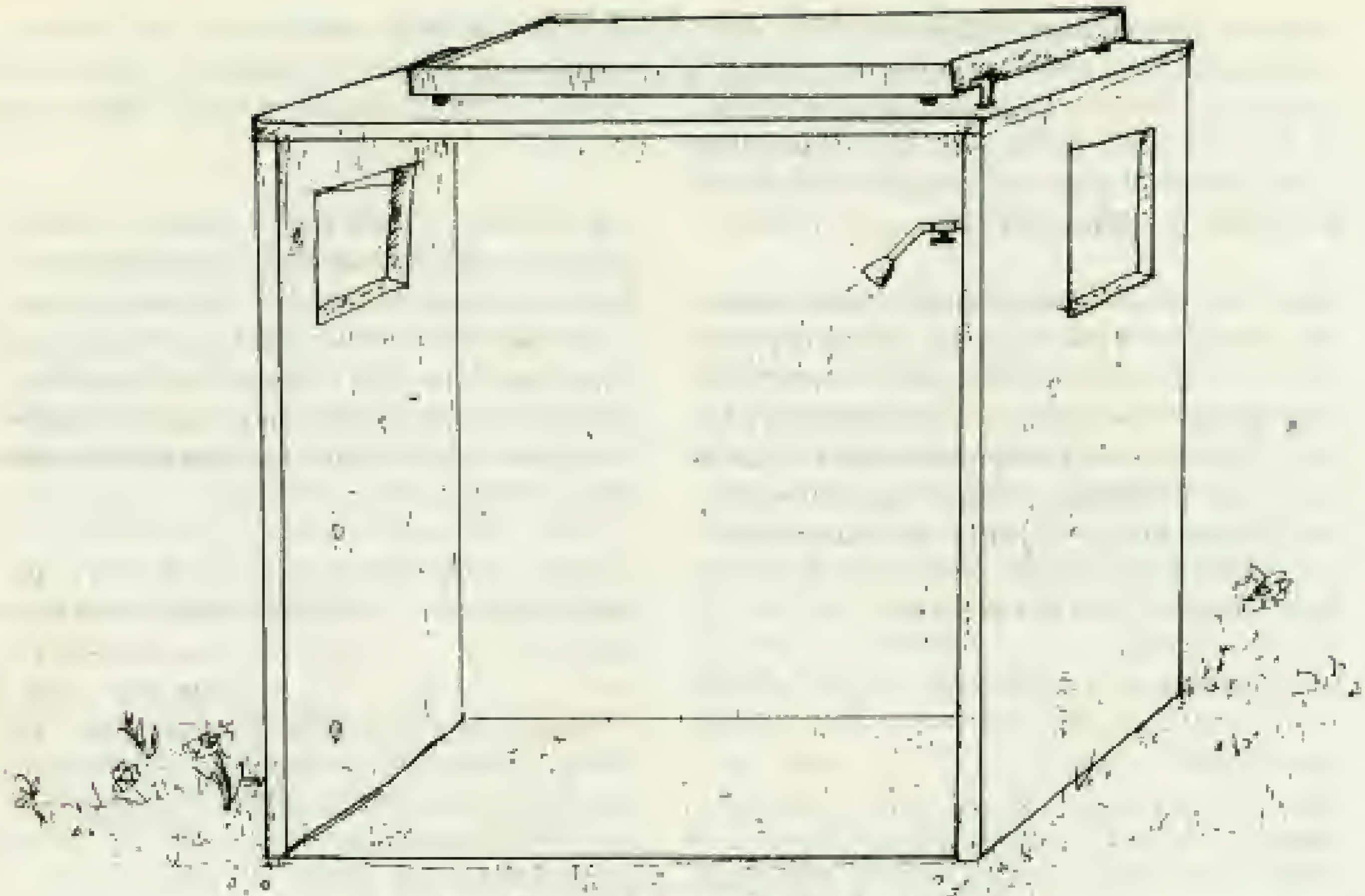
This simple system has worked without
hitch for a decade. We highly recommend
It is inexpensive, and works without main[...]
nance. Steve Baer, who has tried for decad[...]
to promote honest, engineered simplici[...]
invented it thirty years ago. Just rememb[...]
to size the tank to your daily solar input a[...]
personal needs.

Please consider taking a few minutes to d[...]
velop your own simple solutions to increa[...]
ing the surface-area-to-water-ratio problem
batch solar water heaters. Cylindrical tan[...]
are easiest to find, but other shapes are b[...]
ter heat exchangers! Greater efficiency equa[...]
longer showers! Check out the amazing d[...]
signs on pages 45-48!

An older design used in rural Japan wor[...]
very well and consists of a simple wood[...]
tray 3' by 6'. The tray is lined with black pla[...]
tic. A double glass cover helps to insulate t[...]
box. The tray is filled to a level of four inch[...]
which makes for 45 gallons of water. The tr[...]
is horizontal, sits on the roof and quite cap[...]
bly provides hot water. The farmer fills it [...]
the morning and drains it as needed after r[...]
turning from work.

We made a Japanese-type solar collector [...]
ripping the fancy guts out of a donated sol[...]
water heater. The students had a great tin[...]
removing the expensive tubes soldered [...]
metal fins. Removing the parts left a simp[...]
tray covered with glass. The expensive par[...]
had developed a leak as they almost alwa[...]
do.

We filled the remaining tray with four inch[...]
of cold water. This large tray had a great[...]
surface-area-to-volume ratio than our o[...]



Japanese Solar Collector on Roof of Shower Stall

favorite heater made from a tank. When we compared results, the Japanese tray was 51% efficient, compared to the tank at 39%. Even though the tray was flat on the ground, not aimed directly at the sun, it was significantly better. And it pointed out how: Simple works! Batch heaters are great, simple, and can be highly efficient. And sometimes simplicity is much, much better than needless complexity.

And Then

Solar works well if there's a lot of sun, like in our summers. But we can't expect a diffuse energy source to heat water or food or homes on earth very well when clouds obscure its warmth. An architect can talk a blue streak about how well a passive solar house will work in the rain. A salesperson can brag about how hot the newest solar cooker can get. But anyone can add up a few numbers and pretty accurately predict solar performance.

Hopefully, *Capturing Heat One* and *Two* have provided you with a feeling for the potency of solar energy. Living with direct solar devices quickly shows the power and limitations of direct use of sunlight. Before building a solar cooker or solar water heater, it serves well to do some simple math to see how the design can be expected to perform. If it is sunny, the apparatus will probably work very well if you have optimized the heat transfer! But solar heat is not magical. When it's cloudy or foggy at Aprovecho we usually turn to the concentrated solar energy in biomass.

Biomass is and will be the concentrated solar battery of the poor. If it is available, wood provides natural warmth and even power for industrial applications. Unfortunately, trying to

replace dependence on biomass with alternatives such as photovoltaics, wind power, water power, etc. is an option available only to the well-to-do. Even solar cooking and solar water heating are very expensive for most poor folk around the world.

If a concentrated solar energy source is used, like wood or other biomass, please remember that using it at a faster rate than it reproduces assures scarcity. Using direct solar is guilt free, but when using stored energy, it is always tempting to use more and more. A forest is wealth, and like wealth, it needs to be guarded. If we use natural resources at less than the rate of growth, forests and all fertility will grow into a balance of plenty again. Using at less than the rate of growth can replenish the land, seas, and all that grows there.

When humans are selfish and use more than grows, our natural wealth and security begin to disappear and life becomes harder. We presently live in such a condition. We live [in a] world that we have emptied of animals [and] plants, of buried riches, even of clean w[ater] and air.

A good farm shows the world that hu[man] habitation can be beneficial. A good city [can] show the same, as well. One human life [can] demonstrate sustainable practices or no[t. As] time passes, human activity and the har[m it] creates focus attention upon each perso[n as] a steward of this planet. When harm [has] ceased, then harmony can become organi[c,] normal, and lawful. Self-inflicted human [suf]fering will be historical proof that min[dful] stewardship is a trust fulfilled by a matu[re] species.

We sincerely hope that the *Capturing H[eat]* series is useful to you and yours. Please [visit] us whenever you can. If possible, stay to [de]sign, work, and learn with us for ten we[eks] as an intern. Or check out the Aprove[cho] homepage at http://www.efn.org/~apro[...]

Larry Winiarski and two friends from Kenya with a Sudanese Water Heater

Order Form

Please send me
___copies of *Capturing Heat One*, $7 postpaid
___copies of *Capturing Heat Two*, $8 postpaid
___copies of *Capturing Heat Three*, $8 postpaid (available in summer 2000).

___Enclosed is my $30 Aprovecho membership contribution.
___I would like to make an additional donation to Aprovecho's work: $_____.

Name______________________ Phone______________________
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City, State, Zip______________________

Aprovecho is a non-profit, membership-supported organization. Dues are $30 per year and include a newsletter detailing results of current research.

We also offer a ten-week internship program for people who want to learn about organic gardening, sustainable forestry, indigenous skills, and appropriate technology. Sessions begin in March, June, and September in Oregon. Classes (9 am-5 pm Monday through Friday) include lectures, discussion, practical work, and field trips. Please contact Aprovecho for complete information.

Our phone number is (541) 942-8198; fax (541) 942-0302. Please call in advance of your visit. If you would like written information, please send a SASE to Aprovecho Research Center, 80574 Hazelton Rd., Cottage Grove, OR 97424. Or you can check out our website: http://www.efn.org/~apro

Aprovecho Research Center

Aprovecho is a center for research, experimentation, and education on alternative technologies that are ecologically sustainable and culturally responsive. Our fields of study include organic gardening, sustainable forestry, indigenous skills, and appropriate technology. The center is located on a beautiful 40 acre land trust near Eugene, Oregon.

Since 1976, Aprovecho Research Center has been involved in developing energy-efficient and non-polluting inventions that reflect current research but which are designed to be made in most any country. The tools are designed to be self-built and self-repaired. The technologies are used at the Research Center. Students and staff are constantly working to improve designs for efficiency, ease of use, and general utility.

Aprovecho is largely supported by its internship program. Three ten-week semesters are offered per year. Classes are both lecture and hands-on, providing the college-aged or older student a chance to live in and learn with a community of teachers dedicated to sustainable living and voluntary simplicity. Please contact us for further information.

Additional copies of this book are available for $8 postpaid from Aprovecho Research Center, 80574 Hazelton Rd., Cottage Grove, OR 97424, (541) 942-8198. Copies are available for the cost of postage to those working to benefit the poor.